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U. S. ARMY

TRANSPORTATION RESEARCH COMMAND

FORT EUSTIS, VIRGINIA

AD 824351

CRASH INJURY INVESTIGATION

U.S. ARMY

HU-1A BELL IROQUOIS HELICOPTER ACCIDENT

East St. Louis, Illinois

21 October 1959

(Second Printing)

Contract DA-44-177-TC-624 *TCREC Technical Report CRD 2859*

prepared by:

AVIATION CRASH INJURY RESEARCH

PHOENIX, ARIZONA

A DIVISION OF

FLIGHT SAFETY FOUNDATION, INC.

NEW YORK, NEW YORK

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U. S. ARMY HU-1A BELL IROQUOIS HELICOPTER 58-2080
East St. Louis, Illinois
21 October 1959

Report of Accident Investigation
AvCIR -10-PR-110
January 1960

for

U. S. Army
Transportation Research Command
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SUMMARY

An Army HU-1A Bell Iroquois helicopter crashed while on a demonstration flight at Parks Air College, East St. Louis, Illinois, 21 October 1959. The tail boom and the engine tore free at successive impacts, and the roof was crushed into the cockpit and cabin when the helicopter came to rest inverted. The pilot sustained serious injury; the crew chief, minor injury. No other persons were aboard.

A crash injury investigation conducted by Aviation Crash Injury Research found that (1) the seat and cushion contributed to the amplification of the crash force imposed upon the pilot; (2) the structure supporting the roof was not strong enough to prevent the roof from crushing into the cockpit and cabin under survivable crash force conditions.

The investigation found also that (1) the skids and cross tubes seem to have absorbed a considerable amount of crash force; (2) the doors broke off and allowed large exits for escape; and (3) the fuel cells are located in an area not highly subject to impact damage.

As a result of the above findings the attention of responsible military authorities is called to the following recommendations: (1) Immediate steps be taken toward increasing the integrity of the roof structure of this type helicopter. (2) Any seats used should offer their occupants a high degree of energy absorption.

BACKGROUND

On 21 October 1959 an Army HU-1A Bell Iroquois helicopter crashed at Parks Air College Airfield, East St. Louis, Illinois. Both occupants, pilot and crew chief, were injured. A crash injury investigation of the accident was conducted on 23-24 October by Aviation Crash Injury Research (AvCIR) under the provisions of Transportation Research Command Contract No. DA 44-177-TC-624.

The investigating team was handicapped to a degree by the fact that the wreckage had been removed from the scene of the crash and dismantling operations had been started. Nevertheless, photographs of all essential components and equipment were obtained. In addition, photographs available from Army photographers in relation to gouges in the ground and aircraft damage details, together with a graphic plot of wreckage distribution, made it possible to reconstruct the kinematics of the crash sequence. Statements of witnesses and of the pilot and the crew chief helped further in the estimation of flight path velocity, impact conditions, stopping distances, and, finally, the principal vertical and horizontal forces during the crash.

This is the Final Report on the crash injury investigation; it includes both a crash injury analysis and crashworthiness comments. The report is documented by photographs, including an unusual set depicting the crash sequence.

DESCRIPTION OF THE ACCIDENT

GENERAL

A U. S. Army HU-1A Bell helicopter (Iroquois), Serial No. 58-2080, engaged on a demonstration and recruiting mission, crashed while on a flight before a group of air college students and instructors at Parks Air College Airfield, East St. Louis, Illinois, at 10:55 Central Daylight Time, 21 October 1959.

The helicopter had completed a high-speed run parallel to and in front of the spectators, when the pilot initiated a cyclic climb to approximately 500 feet above the terrain to prepare for an autorotative descent. Upon arriving at the desired altitude he made a 180-degree turn. With a forward velocity of 30 to 40 knots, he reduced power, lowered the nose of the aircraft, and entered autorotation. Immediately after entering the maneuver the pilot noted an unusually high rate of descent. At a point estimated to have been 200 feet above the terrain he leveled the aircraft and applied full power and collective pitch, but he was unable to decrease the high rate of vertical descent. Realizing that a crash was inevitable, he continued application of power and pitch and, just prior to the crash, succeeded in partially reducing the high "sink" rate. (See Fig. 1 below for aerial view of accident scene.)

Fig. 1. The aircraft approached the field as indicated by the arrow.

Still in a level attitude, with an estimated flight-path velocity of 40 to 50 knots, the aircraft crashed in a flat, heavily sodded, open area a short distance southeast of the compass rose on Parks Airfield. At impact the tail boom began shearing loose and tore completely free as the aircraft rebounded into the air. The aircraft struck the ground two more times, finally coming to rest approximately 420 feet from the point of initial impact. During this sequence the engine tore free from its mounts and rolled far to the right of the crash path. Cargo and cabin doors were torn free. The main transmission, mast, and rotor assembly tore free during the rolling of the aircraft near the end of the crash path. When the aircraft came to rest inverted, the roof failed in compression, collapsing against the seat backs of the pilot's and the crew chief's seats.

The pilot and the crew chief, the only occupants aboard the aircraft, survived the accident. The pilot sustained a serious lumbar spinal injury; the crew chief sustained only minor injuries. (For detailed medical reports, see Appendix I). Both crew members were wearing safety belts but not shoulder harnesses or hard hats.

CRASH SEQUENCE

The helicopter struck the ground in a level attitude with an estimated flight path speed of 40 to 50 knots and a rate of descent of approximately 1600 to 2000 feet per minute. (See Figs. 2-7, pp. 6-8 for photographs showing helicopter crashing). This was computed from the estimated flight path speed and the angle of impact (18 to 23 degrees). The tail boom sheared from its upper attachment points to the fuselage as the aircraft hit the ground and then tore completely free as the aircraft rebounded into the air. As the fuselage began to rotate to the right (clockwise) the right side of the boom impacted the aft end of the right landing skid.

Gouge marks, damage details, and photographic interpretation indicate that the bottom of the fuselage struck the ground at the initial impact. (For gouge marks, see Fig. 8, p. 9). The skids and cross tubes seem to have absorbed a considerable amount of crash force. Rebounding from the initial impact, the aircraft was in a 20- to 25-degree nose-down attitude, yawing to the right. The left and right forward doors, torn partially free in the impact, were thrown completely free during this rebound.

The aircraft struck the ground a second time at a point 238

feet from the point of first impact. Its attitude at the second impact was slightly nose down, yawed approximately 200 degrees to the right of its original heading, and rolled slightly to the right. At this impact the engine tore completely free from its mounts and was hurled aft, upward, and away from the left side of the aircraft, as the aircraft continued to yaw to the right. (See Fig. 4, p. 7, for photograph showing engine being hurled free). The engine bounced and rolled to the right of the crash path. The main transmission was structurally weakened at the second impact, although it remained attached to the aircraft. The left cargo door was thrown from the aircraft at this time; it came to rest to the left of the crash path.

The aircraft bounced back into the air from the second impact, remaining airborne for 122 feet before it struck the ground for the third time (about 360 feet along the crash path). While the aircraft was airborne it was yawing to the right (clockwise), rolling to the left, and had its nose down 5 to 10 degrees. At third impact the aircraft was yawed approximately 300 degrees to the right of its original heading, rolled over on its left side 20 to 25 degrees, and still had its nose down 5 to 10 degrees.

Just prior to the third impact the main rotor struck the ground. This contact of the rotor and the third impact of the aircraft which followed almost tore the main transmission free.

As the aircraft rebounded from the third impact, it rolled to the right, and the lower portion of the nose struck the ground. Now on the ground, the aircraft slightly reversed its direction of yaw and continued rolling to the right, beyond an inverted position, partially onto its left side. It then settled back and came to rest in an inverted position, approximately 420 feet from the point of first ground contact. (See Fig. 9, p. 9, for close-up view). During this ground roll the roof structure collapsed into the cockpit and cabin area. The final heading of the aircraft was 270 degrees to the right of its original flight path. The transmission, mast, and blade group, which had failed to the left as a unit, came to rest underneath the aircraft, with the mast extending outward at right angles to the aircraft's left side. (See Figs. 10-12, pp. 10-11. For view of wreckage area, see Figs. 13 and 14, pp. 11-12).

See fold-outs of the vertical and horizontal diagrams of the crash sequence inserted following page 12.

Fig. 2. HU-1A descending to initial impact. Dotted line indicates approximate flight path (determined as closely as possible through photographic analysis). The arrow indicates point of impact.

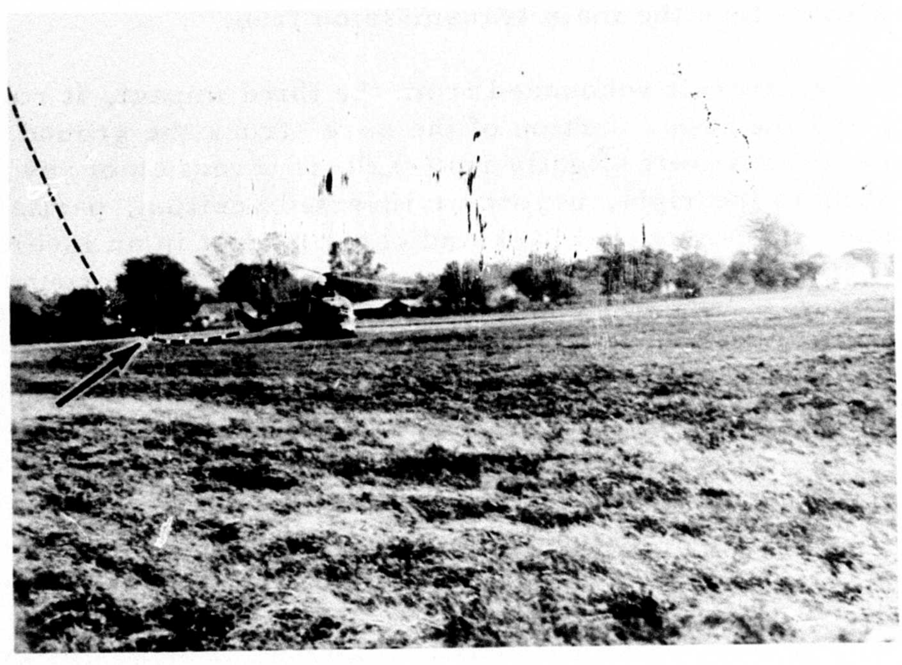


Fig. 3. HU-1A shown rebounding off ground after initial impact. Tail boom is broken downward; fuselage begins turning clockwise. Initial impact gouge indicates aircraft rode on ground at least 12 feet before rebounding back into the air. (Refer to Fig. 8, p. 9).

Fig. 4. View of right side and underside of HU-1A (nose is at the right), airborne after second impact about 350 feet along crash path. Note that engine is torn free, hurtling ahead of fuselage; slight displacement of rotor head to left is indicated.

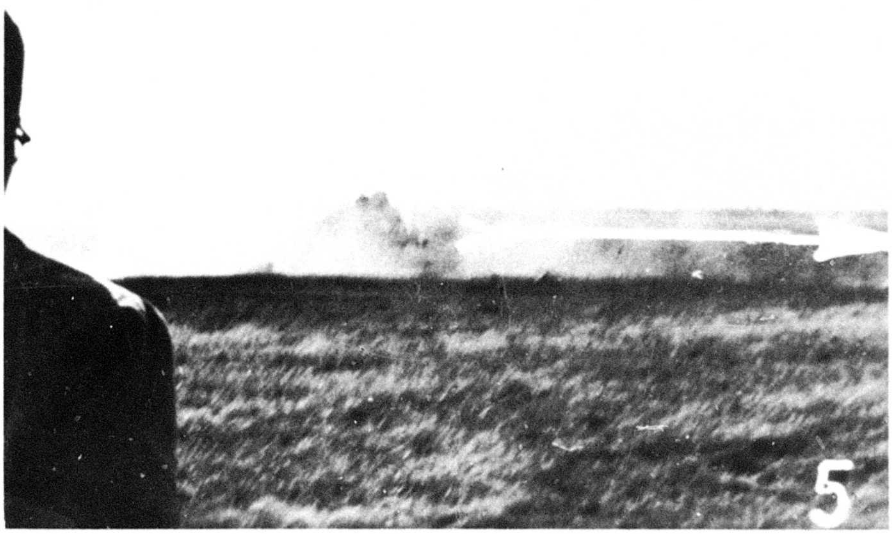


Fig. 5. HU-1A rolling to rest (about 410 feet along crash path). Arrow indicates direction of travel of engine.

Fig. 6. HU-1A at rest (about 420 feet along crash path) inverted.

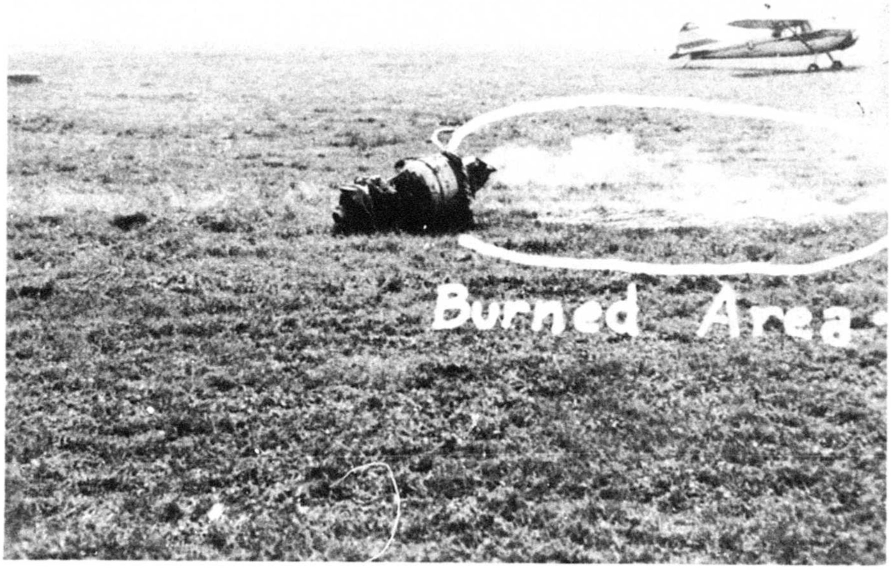


Fig. 7. Engine continued to run for a few seconds after being torn free.

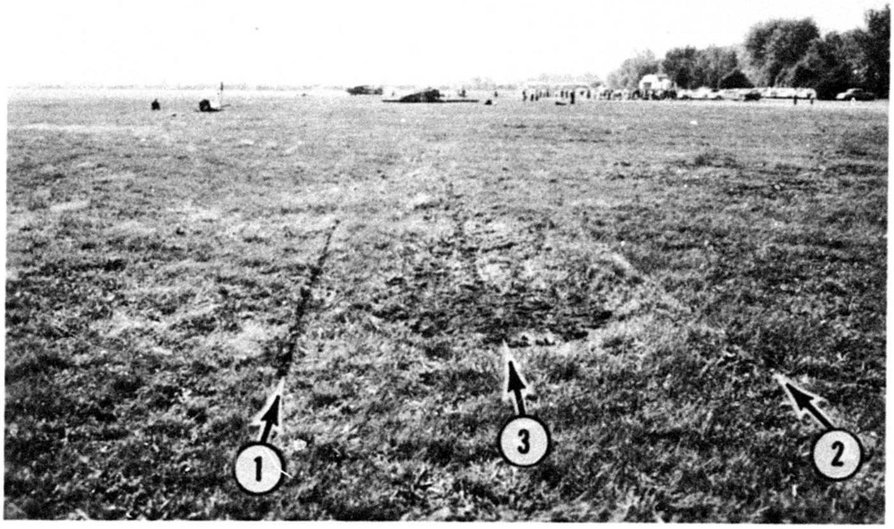


Fig. 8. Initial impact area. Arrow 1 indicates the left skid mark; arrow 2, the right skid mark; and arrow 3, the fuselage gouge.

Fig. 9. HU-1A as it came to rest in an inverted position.

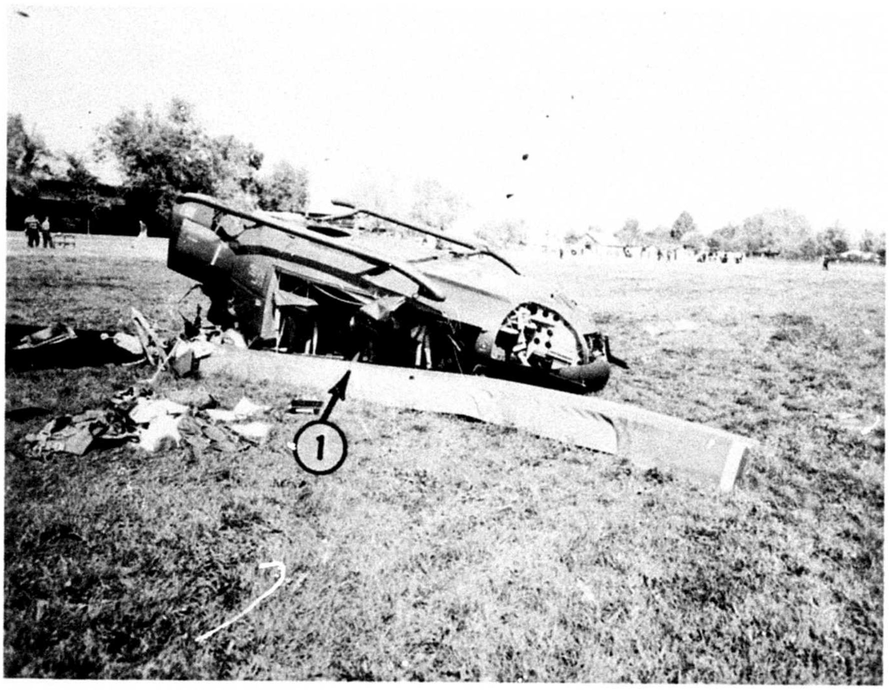


Fig. 10. Left side of aircraft. Transmission and rotor head, mast, and blades were broken to the left (about 90 degrees). Left vertical roof supporting member is also buckled (arrow 1).

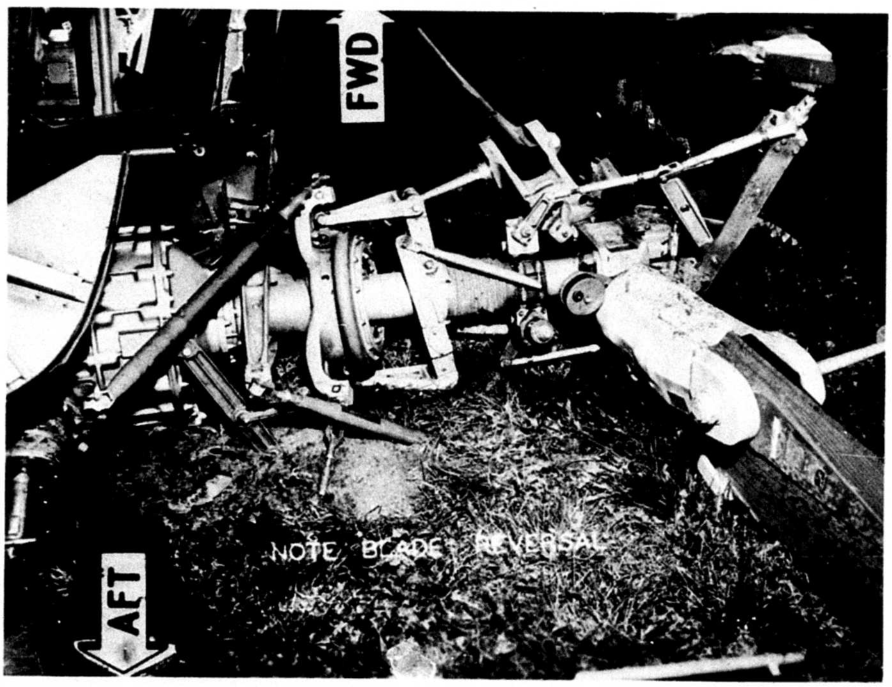


Fig. 11. Transmission, mast, head and blades broke off as a unit to the left.

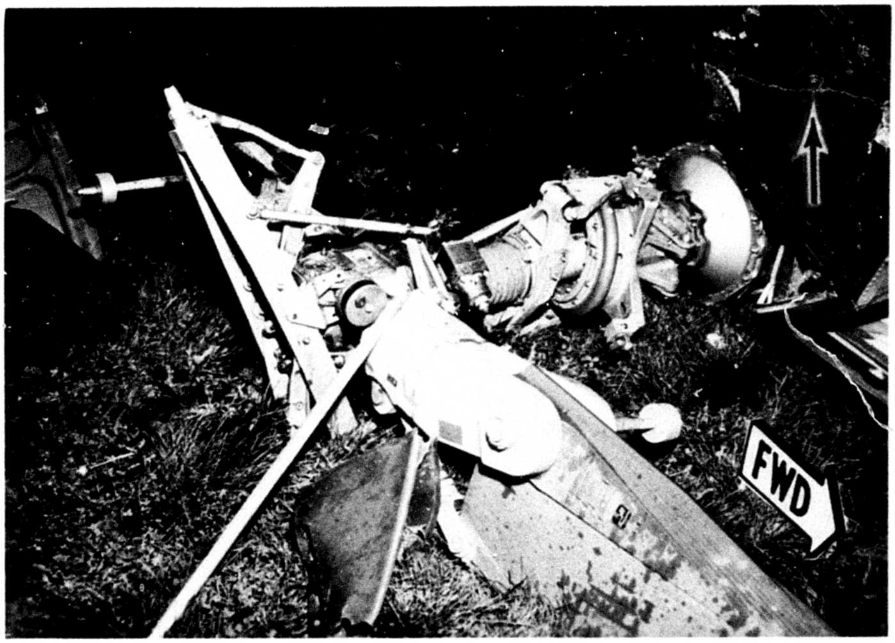


Fig. 12. Transmission, mast, rotor head and blades viewed looking aft. Left fuel cell area is shown (arrow).

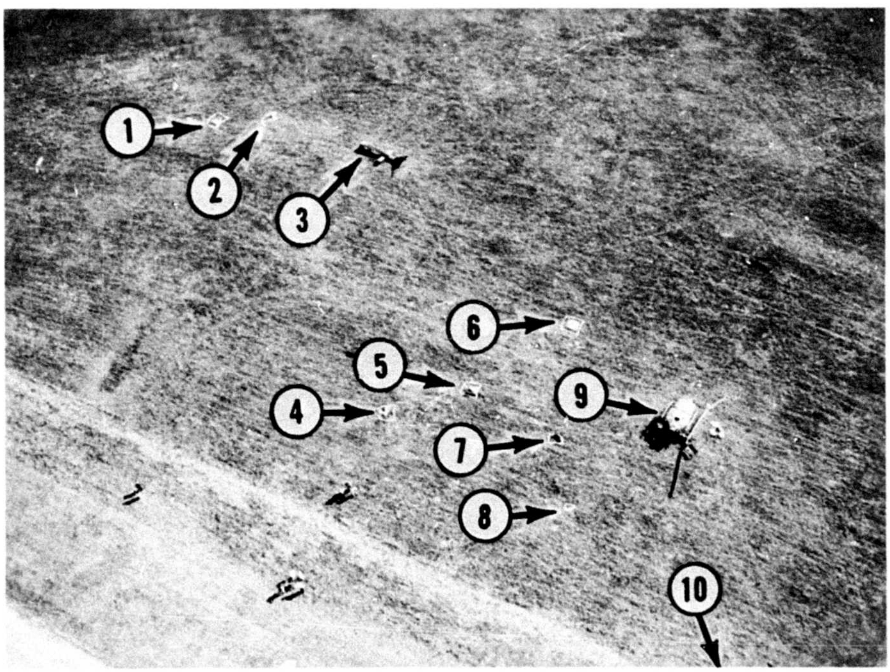
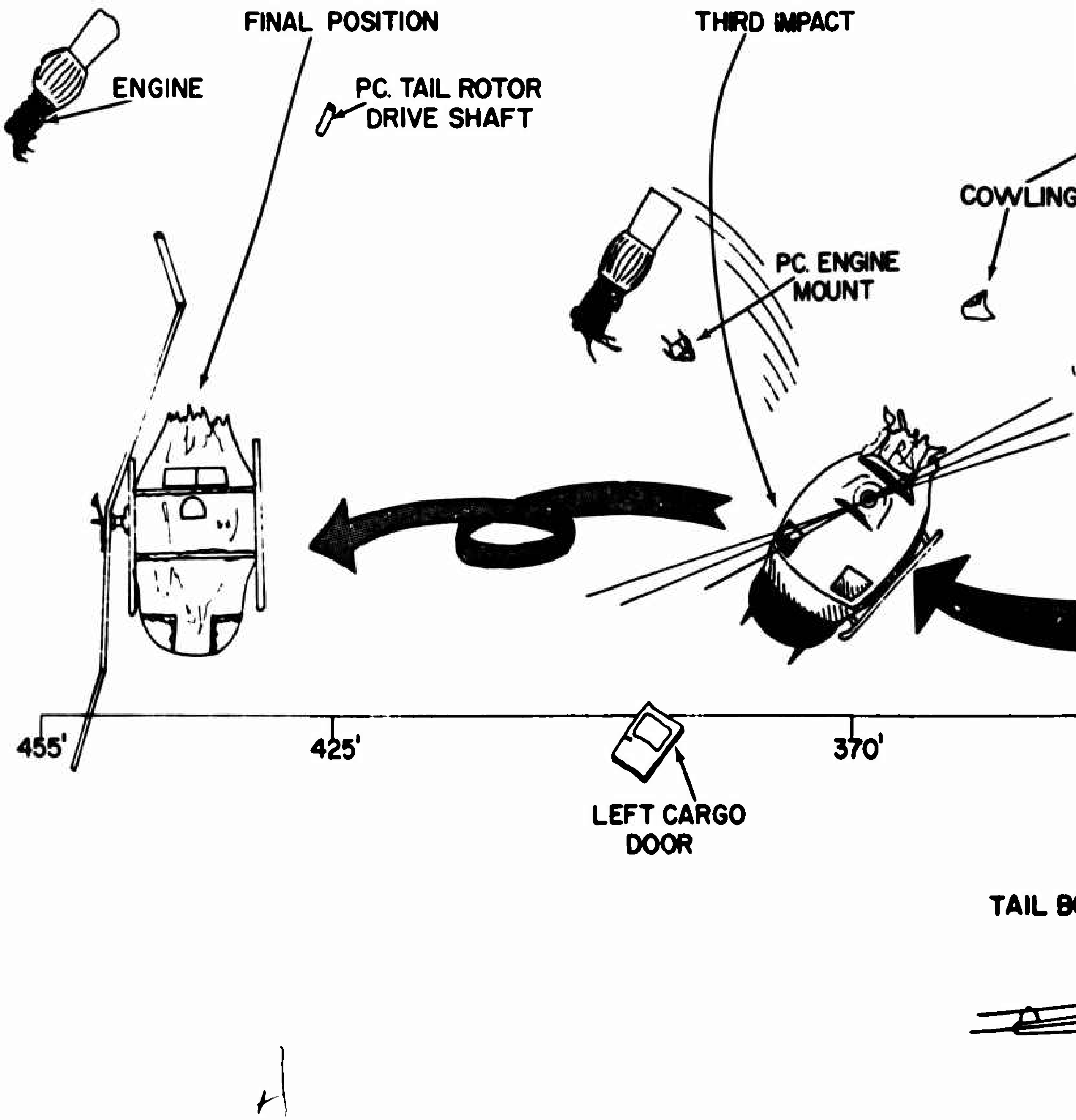


Fig. 13. Aerial view of main wreckage area. Arrows indicate the following: 1, left forward door; 2, right forward door; 3, tail boom; 4, cowling; 5, left engine cowling; 6, left cargo door; 7, cowling; 8, tail rotor drive shaft piece; 9, fuselage; 10, direction of engine.

Fig. 14. Ground view of main wreckage area.



FINAL POSITION
THIRD IMPACT
ENGINE
PC. TAIL ROTOR
DRIVE SHAFT
COWLING
PC. ENGINE
MOUNT
455'
425'
370'
LEFT CARGO
DOOR
TAIL BO

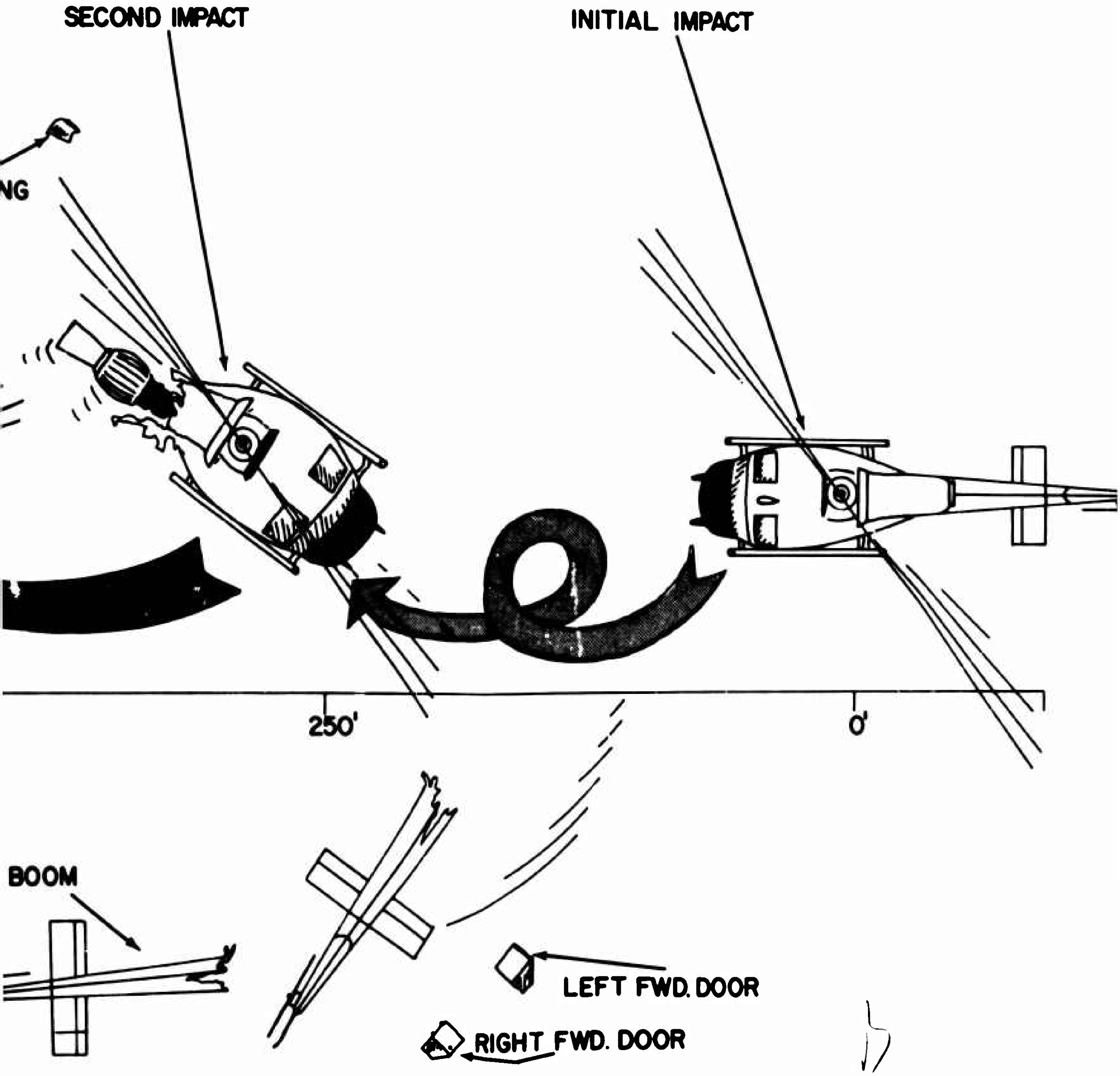
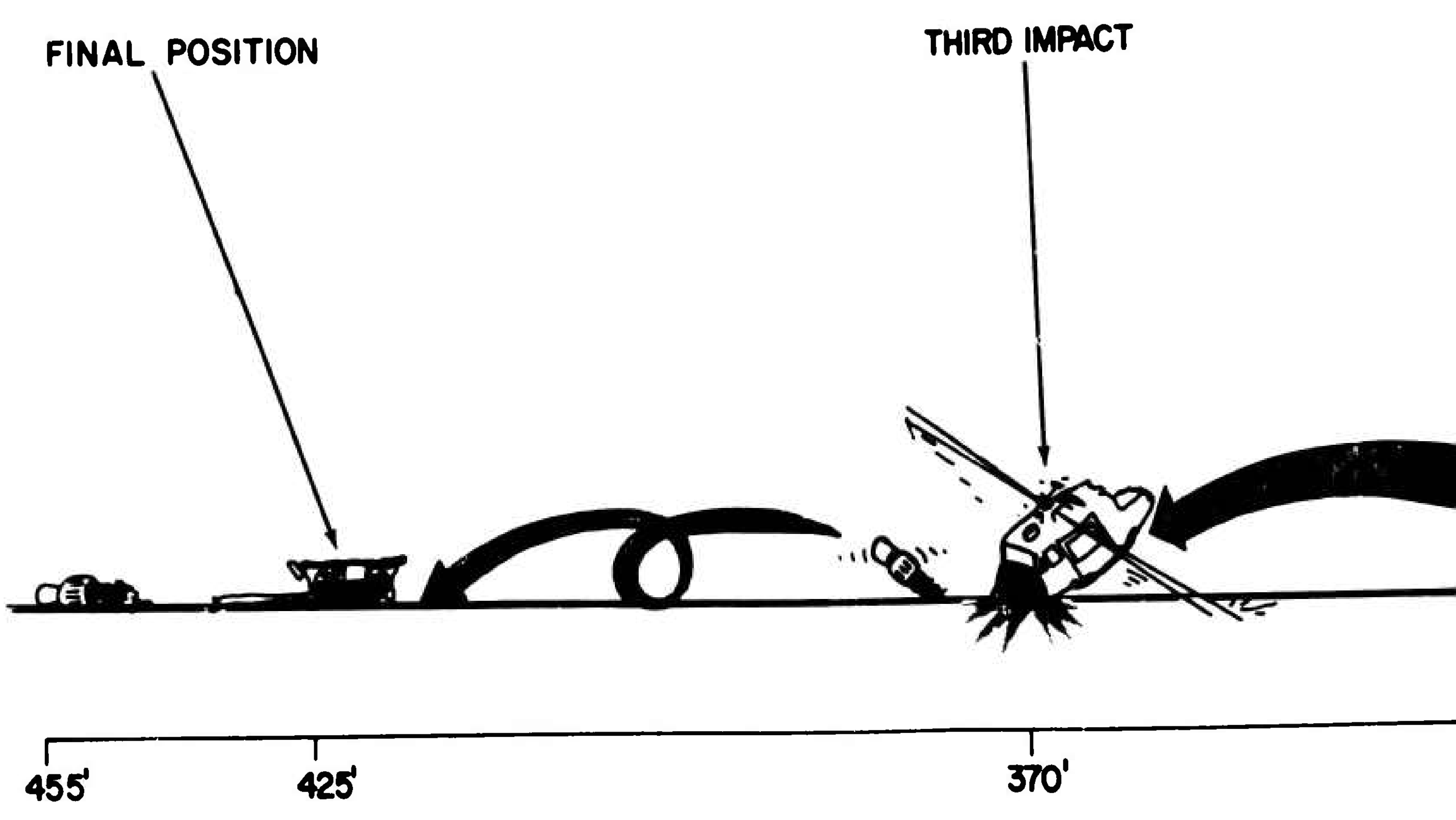


Figure 15. Crash Kinematics Drawing (Top View)


FINAL POSITION
THIRD IMPACT
455'
425'
370'

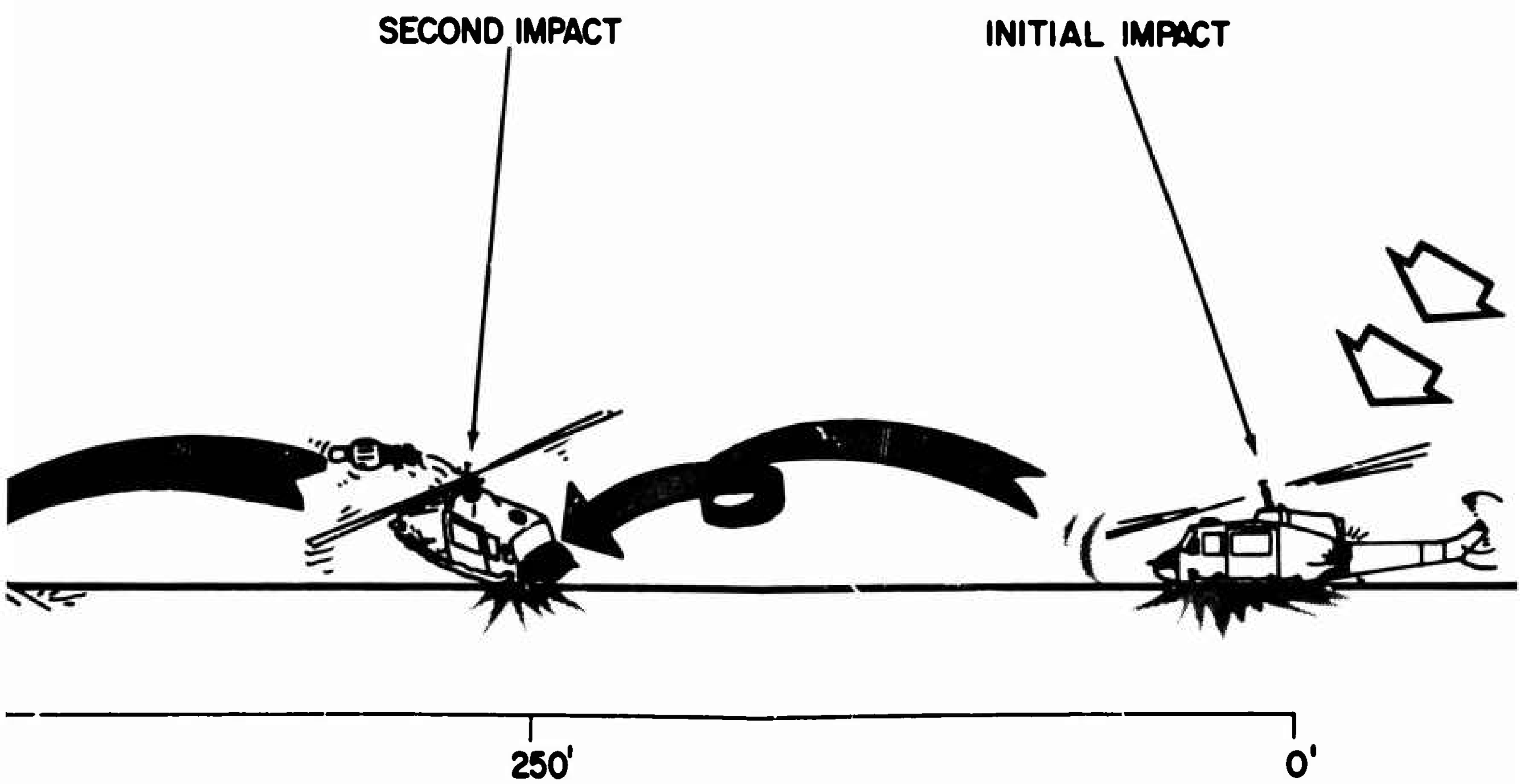


Figure 16. Crash Kinematics Drawing (Side View)

DAMAGE TO THE AIRCRAFT

The cockpit and cabin areas were extensively damaged by the downward collapse of the roof structure onto the top of the pilot's and copilot's seat backs. The overhead structure was also impinging on the second row of seat backs as the helicopter lay in its position of final rest. (See Figs. 17-23, p. 14 ff., for views from various angles). Collapse of the roof was caused by the failure of the left and the right vertical supporting members, which are also utilized as door posts. The collapse of the roof structure allowed the overhead console to move downward and come to rest against the top of the copilot's seat back. (See Figs. 24-25, p. 18). The aft bulkhead was partially collapsed as the aircraft rolled to an inverted position. (See Figs. 16-20, p. 19 ff.)

Both the pilot's and the copilot's doors were torn free during the crash sequence, as was the left cargo door. The right cargo door, although torn partially free, remained attached to the cabin.

The instrument panel, even though loosened by impact forces and displaced slightly forward, sustained very little damage and remained intact. (See Fig. 22, p. 17; Fig. 31, p. 21).

Both the pilot's and the copilot's collective pitch and cyclic controls were undamaged. The pilot's rudder pedals were broken, but the copilot's pedals were undamaged. (See Fig. 32-33, p. 22). The floor structure of the cockpit and the cabin area was completely intact except for some distortion in the vicinity of the pilot's rudder pedals. (For views of floor see Figs. 34-36, p. 23 ff.; Fig. 30, p. 21).

All of the seats in the cockpit and cabin area remained intact and in their normal positions following the crash. However, both the pilot's and the copilot's seats revealed slight distortion to the right. (See distortion in Figs. 37-38, p. 24 ff.) There appeared to be no other damage to the seats.

The roof structure itself remained relatively intact even though it had collapsed into the cabin when the aircraft rolled over. The lower right exterior of the nose section revealed some impact damage (See Fig. 39, p. 25); and the belly section, although intact, was buckled inward and collapsed in the area directly to the rear of the hoist well. (See Fig. 40, p. 26). The structure surrounding both fuel tanks, which are located directly behind the aft bulkhead, was intact. The fuel cells were undamaged. The tail cone was sheared from the fuselage at its upper attachments points. (Sheared cone and attachment points are

shown in Figs. 41-42, pp. 26-27); the entire tail cone and tail rotor tore free as a unit and remained relatively intact. The rear portion of the right skid evidently gouged a hole along the right side of the tail cone as the tail cone was tearing free from the fuselage.

The front cross tube failed during the crash sequence. The rear cross tube remained intact but was badly distorted. Both the left and the right skids, although intact, were pushed upward to a position even with the bottom of the fuselage. (See skid deformation in Figs. 43-44, pp. 27-28).

The engine was torn free and damaged in bouncing and rolling. (For close-up view of engine where it came to rest, see Fig. 45, p. 28). The main transmission, mast, and rotor assembly was partially torn free as a unit. Both the transmission and the rotor blades were extensively damaged.

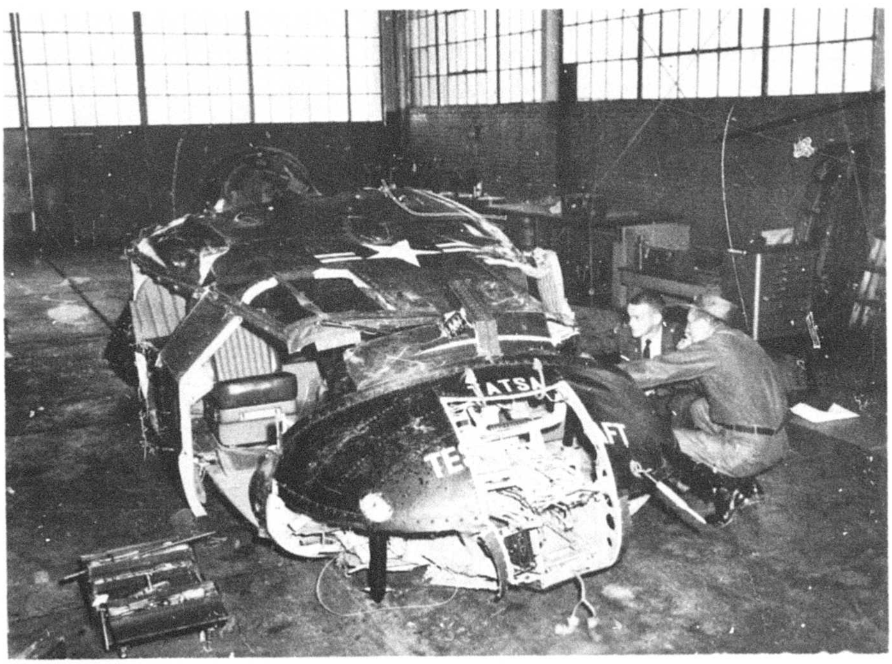


Fig. 17. Front view, aircraft righted. Except for overall inward crushing of the cabin roof, only moderate damage was sustained by the roof structure.

Fig. 18. Right side of fuselage. Note that overhead structure (roof) is impinged on top of the pilot's seat. The windshield wiper motor (arrow 1) was forced downward into the area normally occupied by the pilot's head.

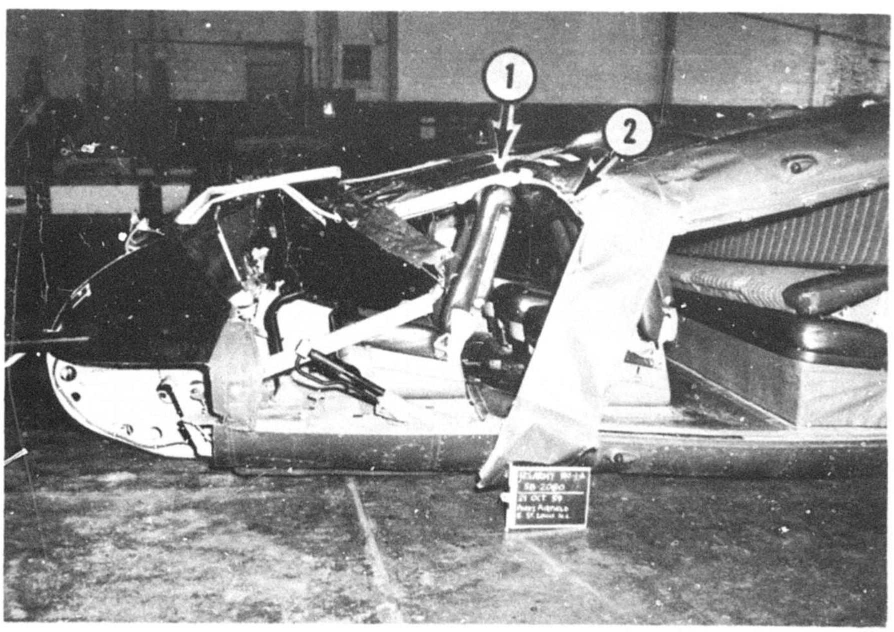


Fig. 19. Left side of cabin. The overhead structure on this side also impinged on the occupiable area. Note that the overhead structure is resting on both the copilot's seat bac (arrow 1) and the second row of seats (arrow 2).

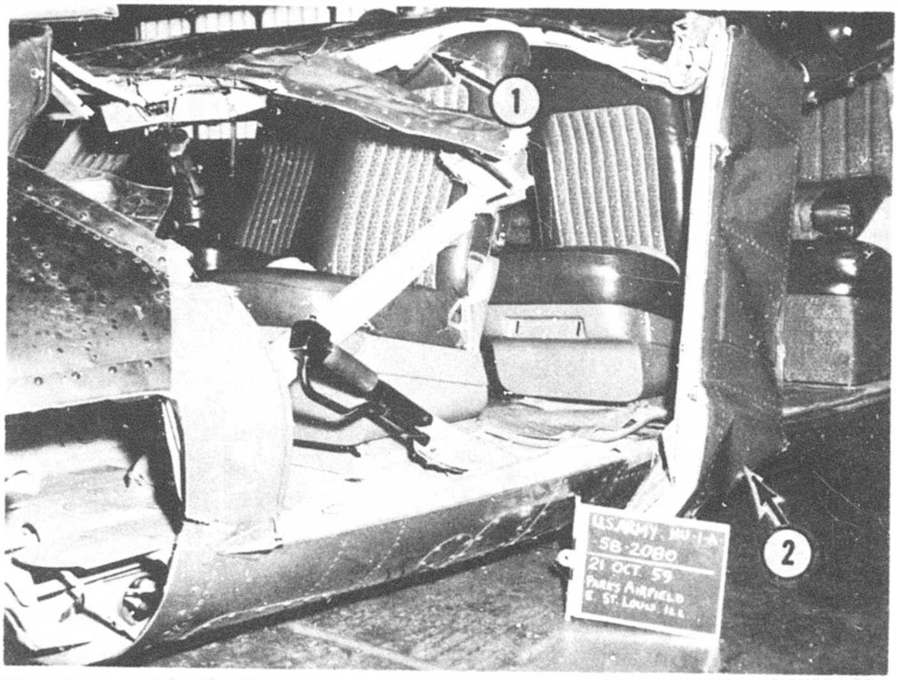


Fig. 20. Left side of cabin. Note that the copilot's seat top is supporting the overhead structure (arrow 1). Note the failure of the vertical support member (arrow 2).

Fig. 21. View of aircraft inverted. Note that roof is impinged on top of passenger seat behind the copilot's seat (arrow).

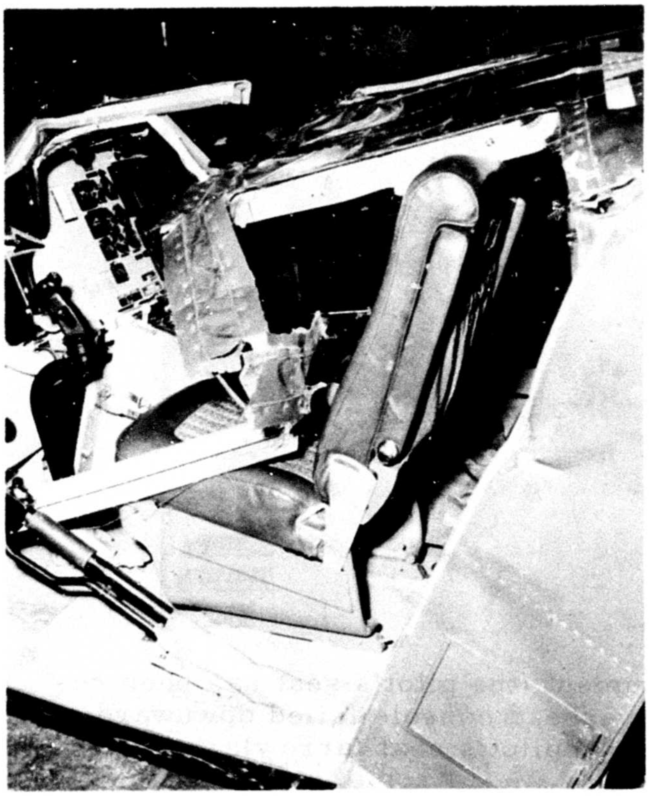


Fig. 22. Instrument panel broke forward (away from occupants) during crash (arrow).

Fig. 23. Copilot's (left) overhead window frame (arrow 1) and left forward door post (arrow 2) were crushed inward.

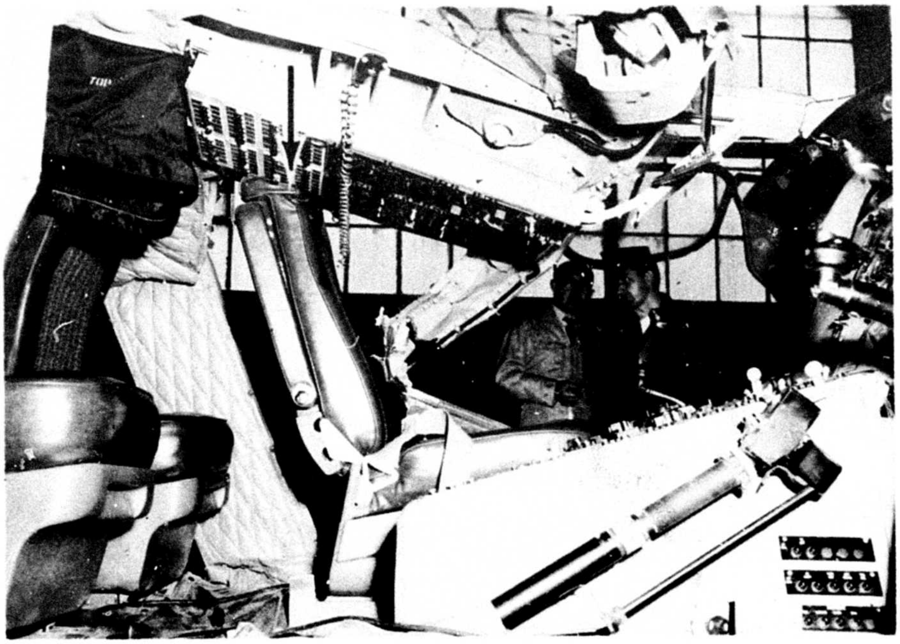


Fig. 24. View of copilot's environment (the pilot's seat has been removed). Note that the overhead console failed downward and impinged on the top of the copilot's seat (arrow).

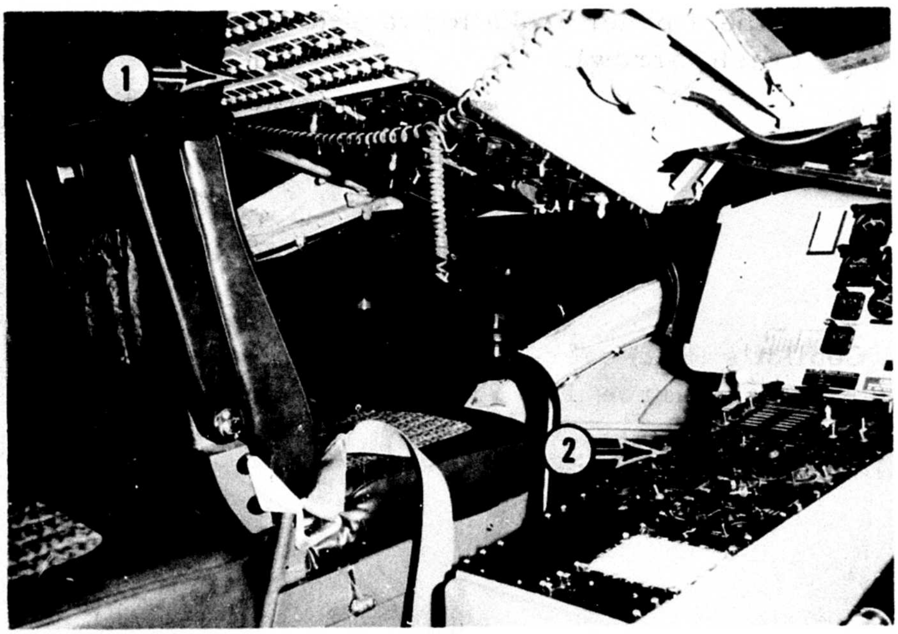


Fig. 25. Overhead console (arrow 1) presents hazardous condition when allowed to crush inward. Lower control console (arrow 2) offers no protection (padding) against injuries, which would be produced through forceful contact. In this accident no serious injuries occurred as a result of this condition.

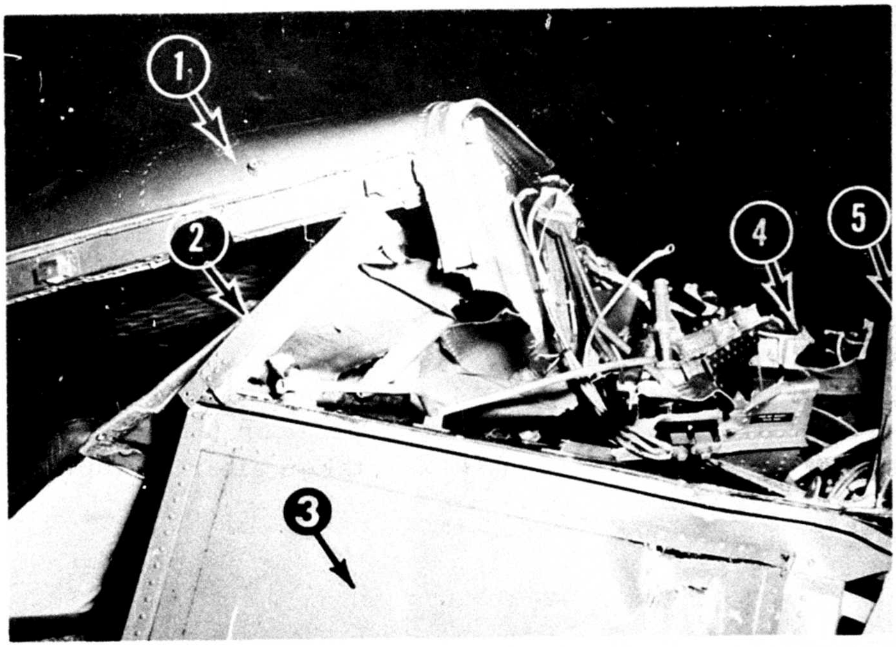


Fig. 26. Left side of HU-1A, showing overhead (roof) structure (arrow 1), aft cabin firewall bulkhead (arrow 2), left fuel cell area (arrow 3), rotor transmission (arrow 4), and forward engine firewall support (arrow 5).

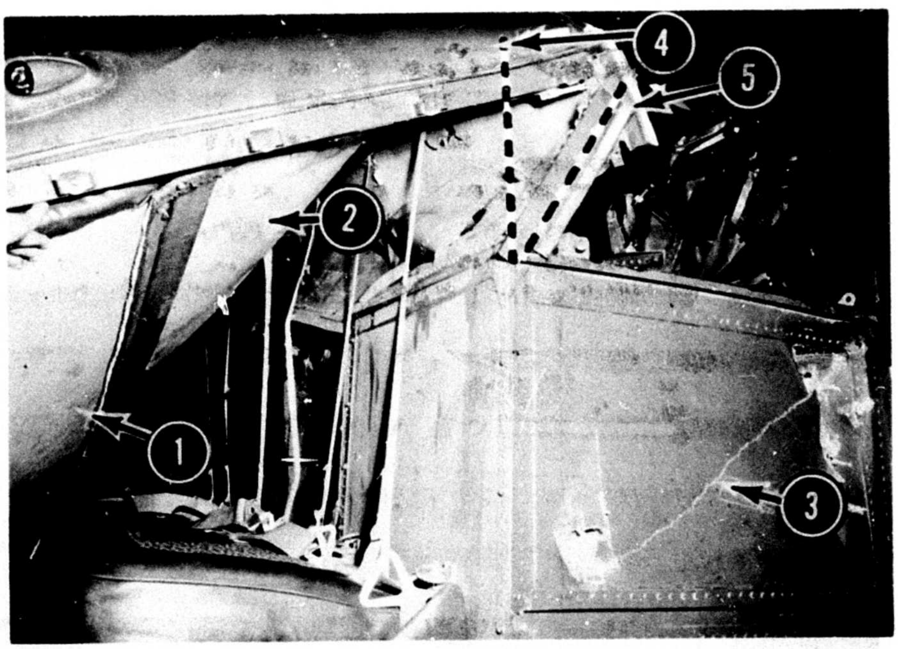


Fig. 27. Left aft cabin. Seat back (arrow 1) and upper padding (arrow 2) are pulled forward exposing aft cabin bulkhead firewall, left fuel cell area (arrow 3). Dotted line (arrow 4) indicates normal configuration of aft cabin upper bulkhead firewall, which is broken and buckled back to position shown by dotted line (arrow 5).

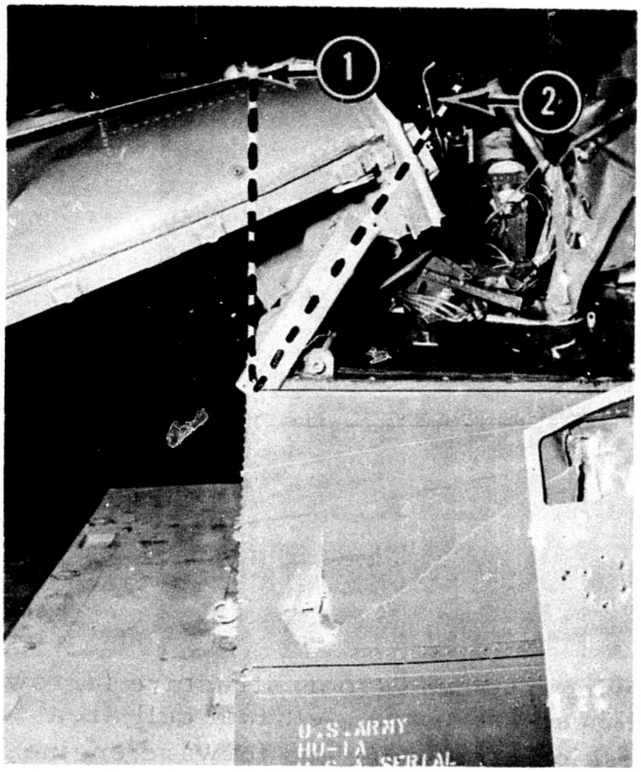


Fig. 28. Normal position of bulkhead (arrow 1); distorted position (arrow 2). Photo taken after stripping of cabin.

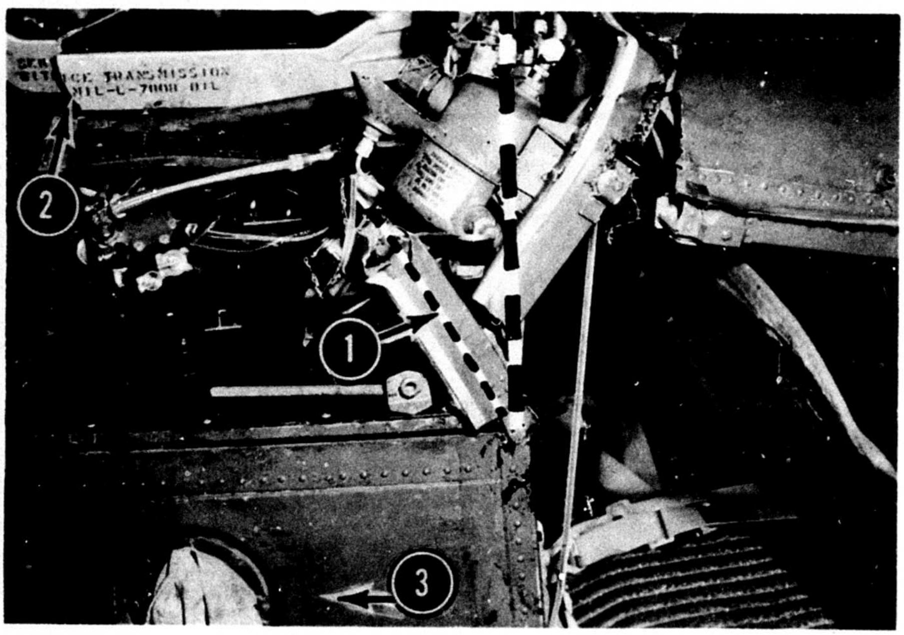


Fig. 29. Right side, aft cabin bulkhead firewall area. Heavy dotted line indicates normal position of firewall frame (arrow 1). Note cracked rotor transmission (arrow 2). Arrow 3 indicates right fuel cell area.

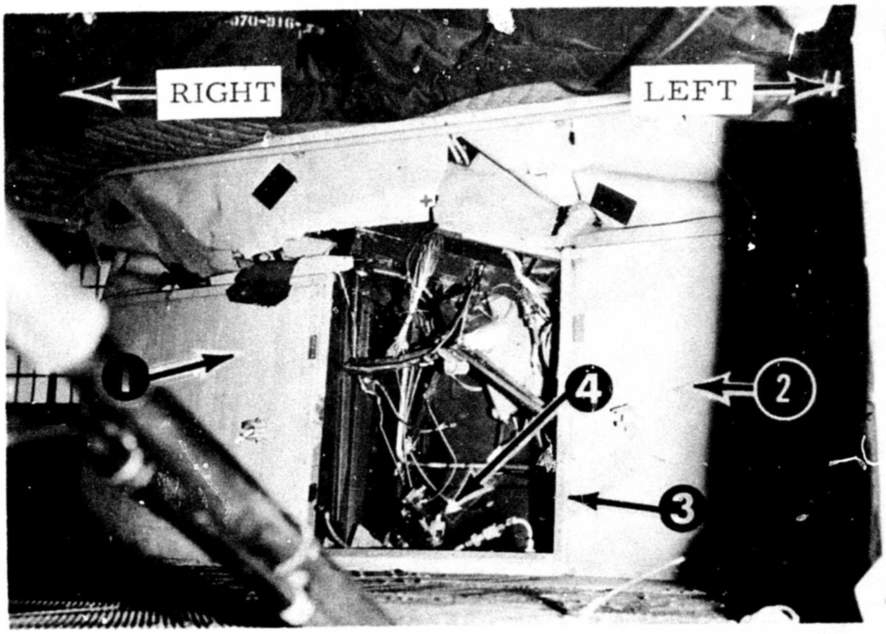


Fig. 30. Aft cabin bulkhead, showing fuel cell area, right (arrow 1) and left (arrow 2). Hoist well (arrow 3) and hoist coupling (arrow 4) are located between fuel cells. Seats and floor covering are removed to reveal intact floor, without the slightest distortion.

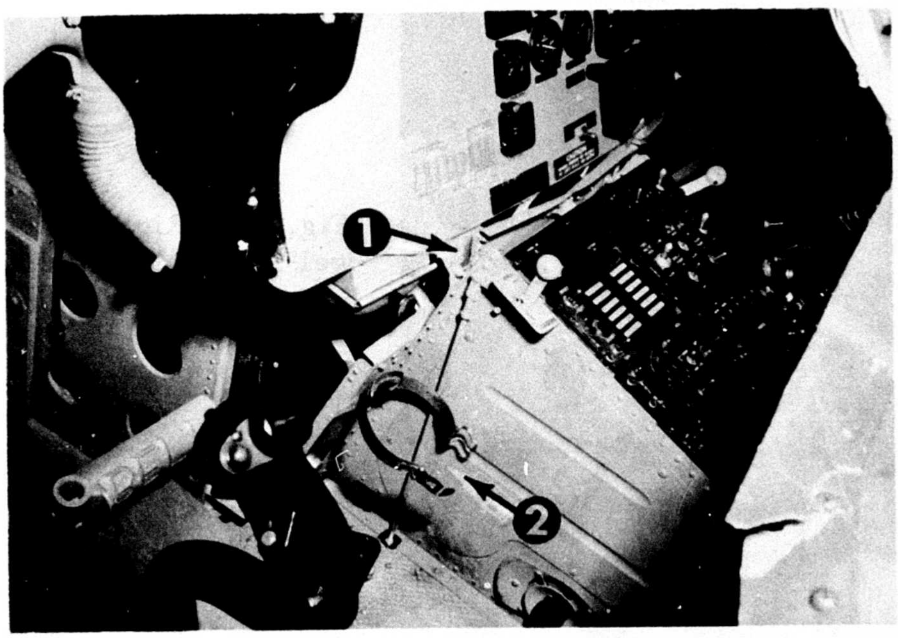


Fig. 31. Instrument panel and control console on copilot's side (left). Note that instrument panel is broken forward, away from occupant (arrow 1). Arrow 2 indicates the fire extinguisher mount.

Fig. 32. Left (copilot) pedal well. Except for broken plexiglass, this structure was relatively intact.

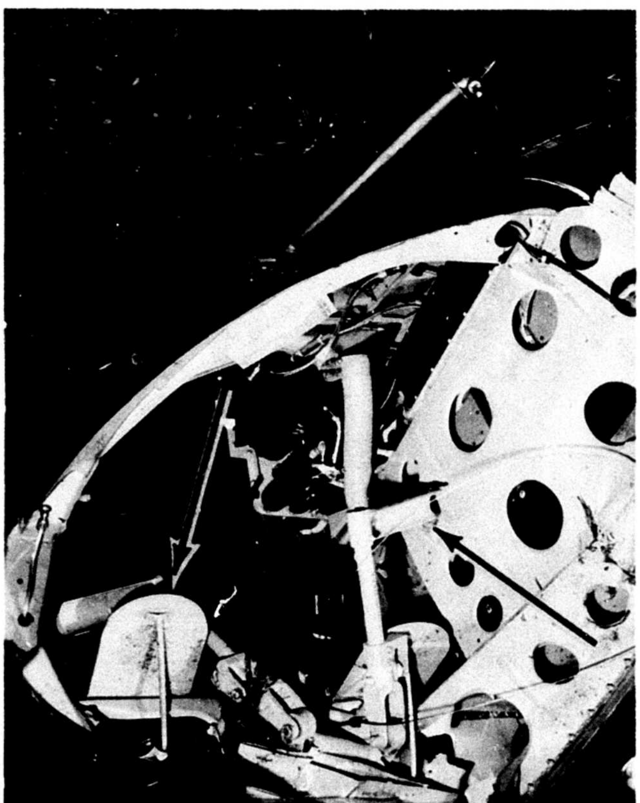


Fig. 33. Right (pilot) pedal well. Pedals (arrows) were broken during gouging.

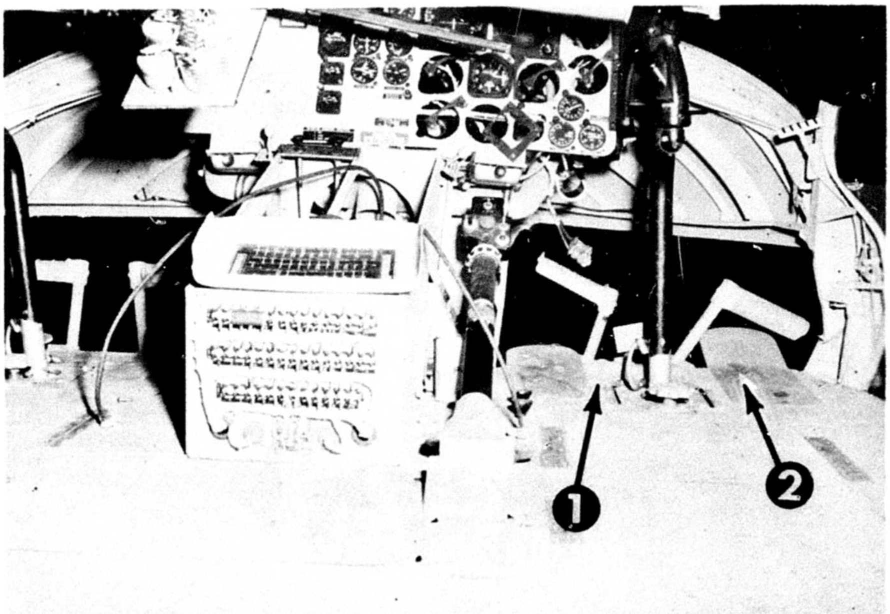


Fig. 34. Cockpit area with pilot's and copilot's seats removed. Note that the floor structure is intact except in that area below the pilot's rudder pedals (arrows 1 and 2). Note the damage to pilot's pedals. (Several instruments and a portion of the console were removed prior to photographing.)

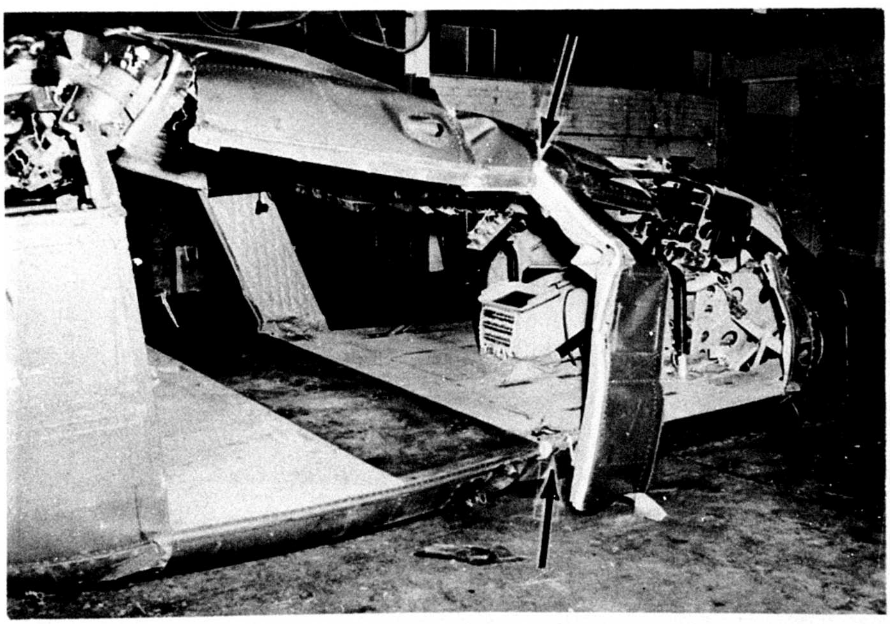


Fig. 35. Right side fuselage (seats removed). Note compression and failure of vertical overhead support member, which allowed overhead structure to crush downward. (See Fig. 67).

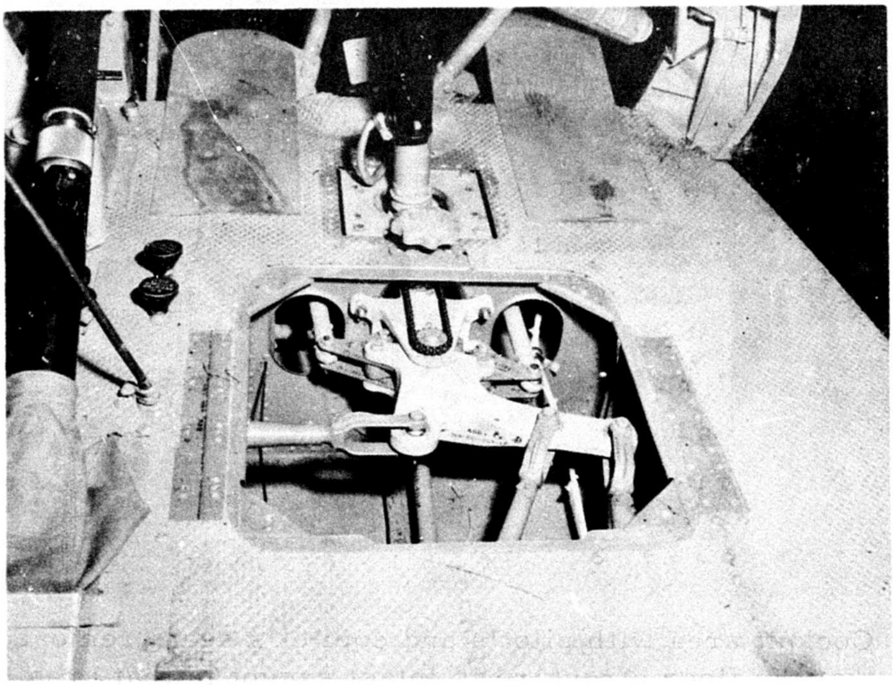


Fig. 36. Right front (pilot's) floor area with control access plate removed to determine whether any hidden damage existed. None was found. Pilot seat mounting plate was fastened to floor over this access area.

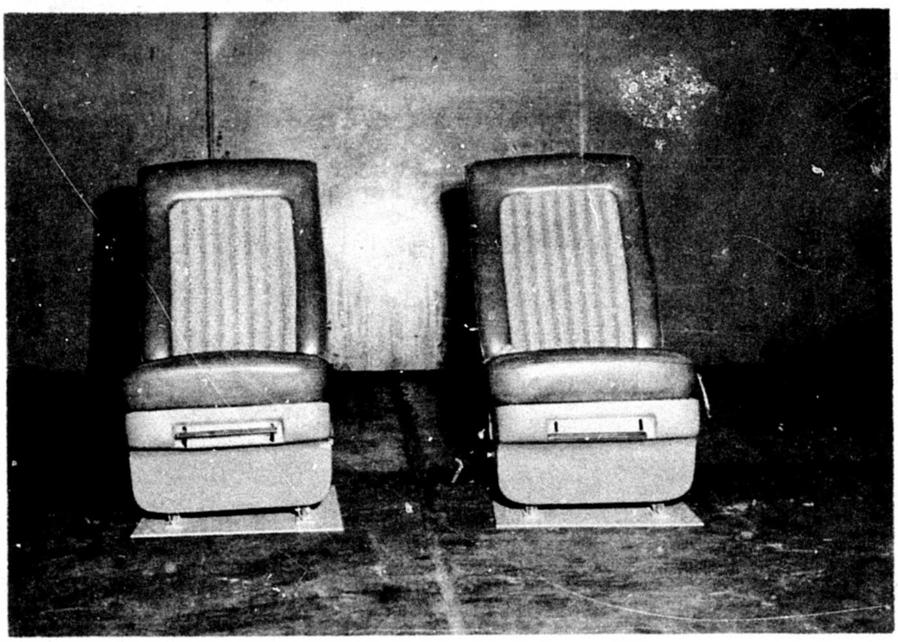


Fig. 37. Pilot (left) and copilot (right) seats - removed from the aircraft. Slight distortion to the right (on both seats) is visible.

Fig. 38. Pilot (right) and copilot (left) seats. Distortion to the right is more noticeable from this view. Note mounting plates used to install this "special" seat in the demonstration HU-1A.

Fig. 39. Front view. Note front right cross-tube failure (arrow). Dotted lines indicate approximate normal cross-tube configuration. Damage incurred to the fuselage is greater on the right side. Although distorted, the rear cross-tube did not fail.

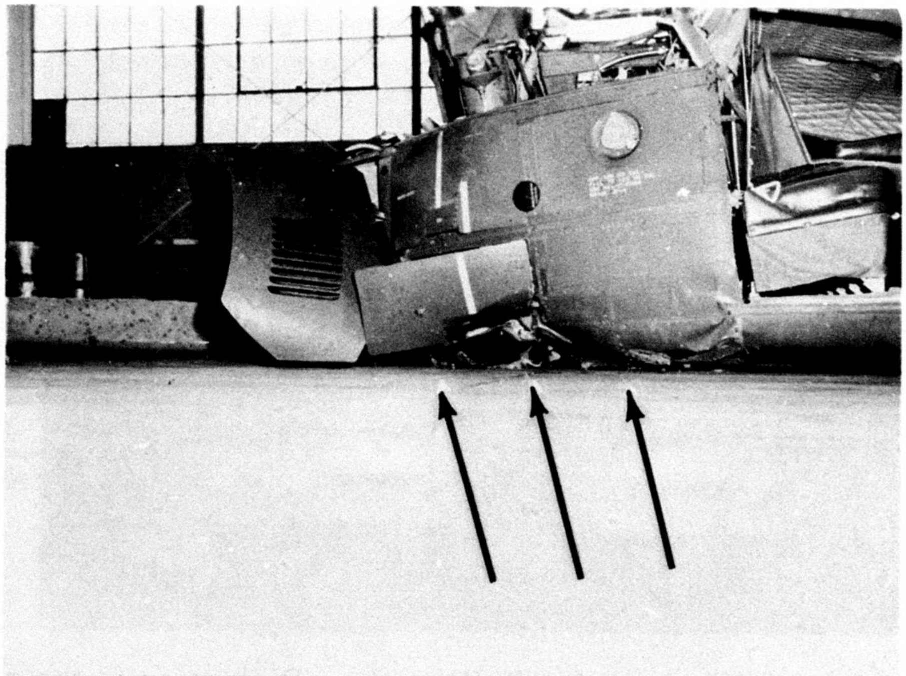


Fig. 40. Aft right fuselage. Arrows indicate fuselage belly area (believed to have been damaged at initial impact).

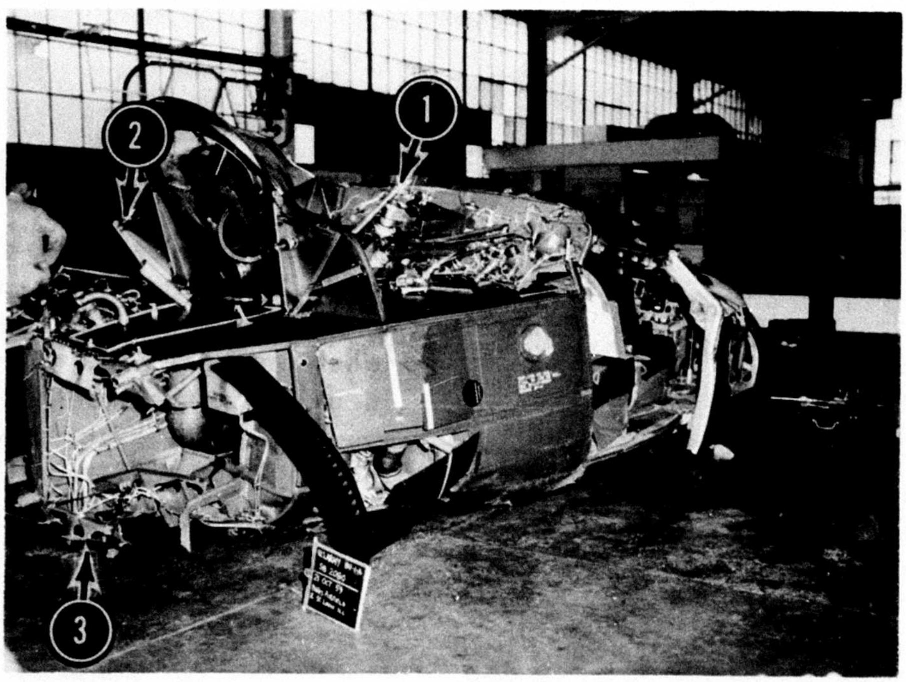


Fig. 41. Aft right fuselage, showing position for rotor mast and transmission (arrow 1), engine area (arrow 2), tail boom attachment (area 3).

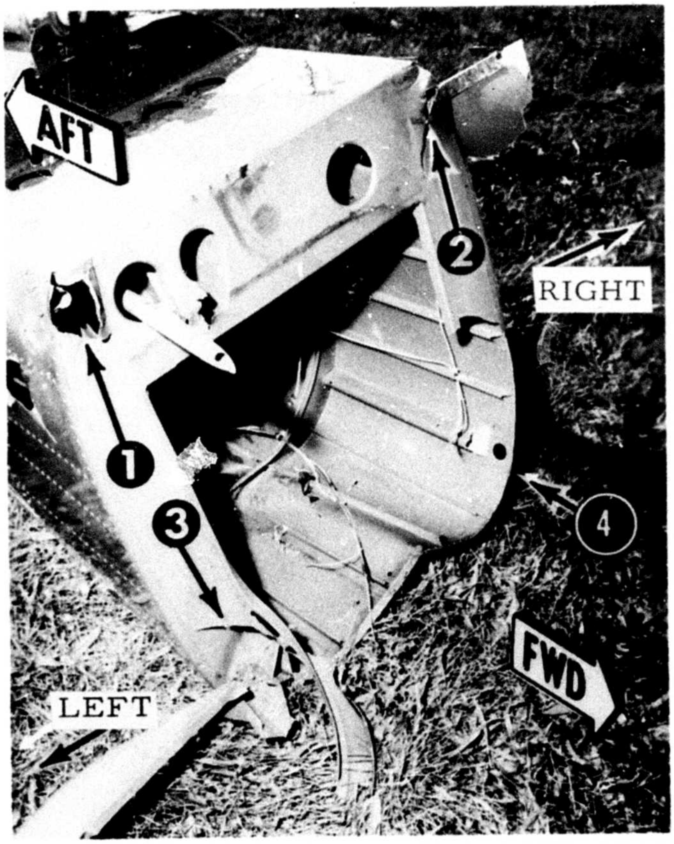


Fig. 42. Forward end of tail boom. Upper right (arrow 1) and upper left (arrow 2) attaching points failed at initial impact - in tension. Lower right (arrow 3) point failure was first in compression, then tension. Lower left (arrow 4) failure was primarily in compression.

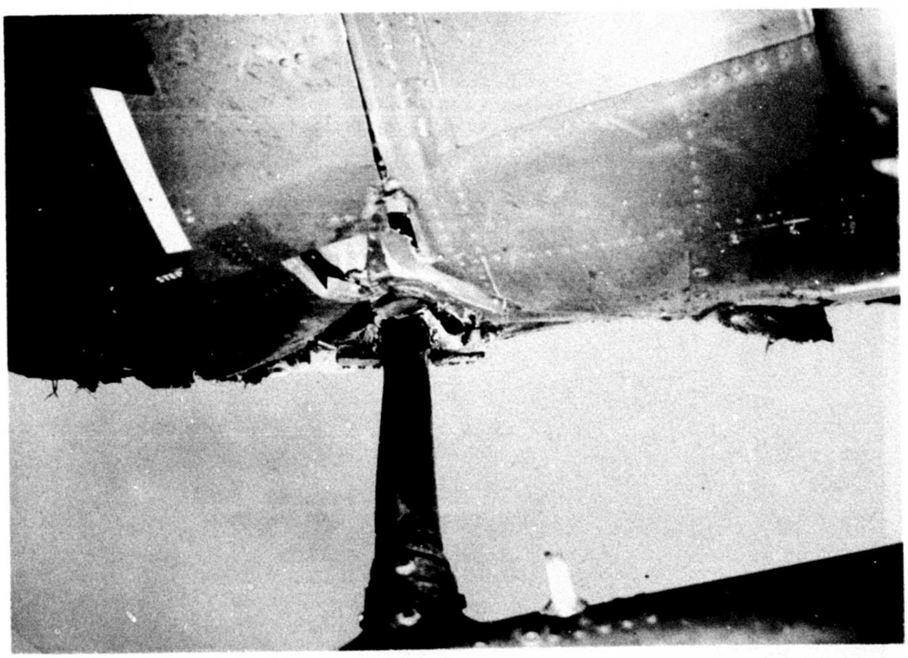


Fig. 43. Left aft cross-tube. Note damage to the fuselage (probably occurred at initial impact).

Fig. 44. Close-up of right front cross-tube failure indicates it had deflected to a great extent, absorbing vertical crash force.

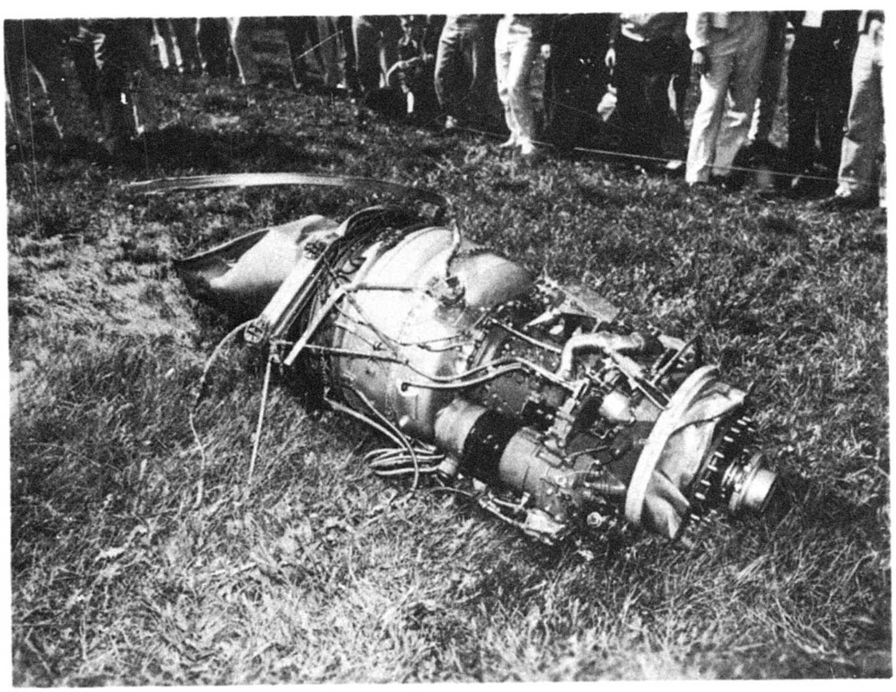


Fig. 45. HU-1A jet engine shown as it came to rest.

Fig. 46. Forward left (not shown) and aft left (arrow 1) engine mounts failed in compression. Center (arrow 2), aft (arrow 3), and forward (arrow 4) engine mounts failed in tension.

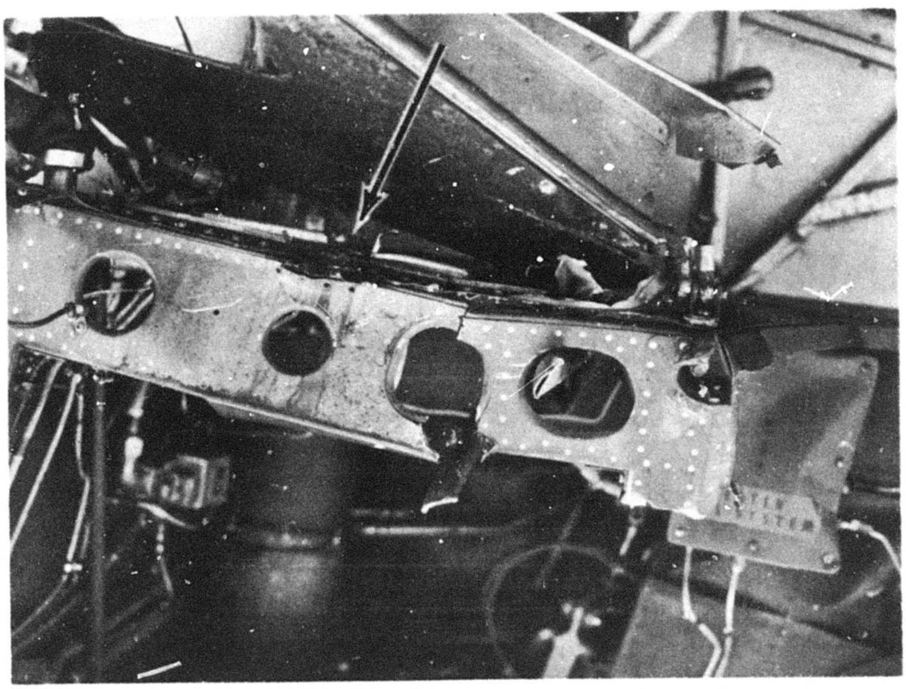


Fig. 47. Center engine mount aft (arrow) was torn free in an upward direction.

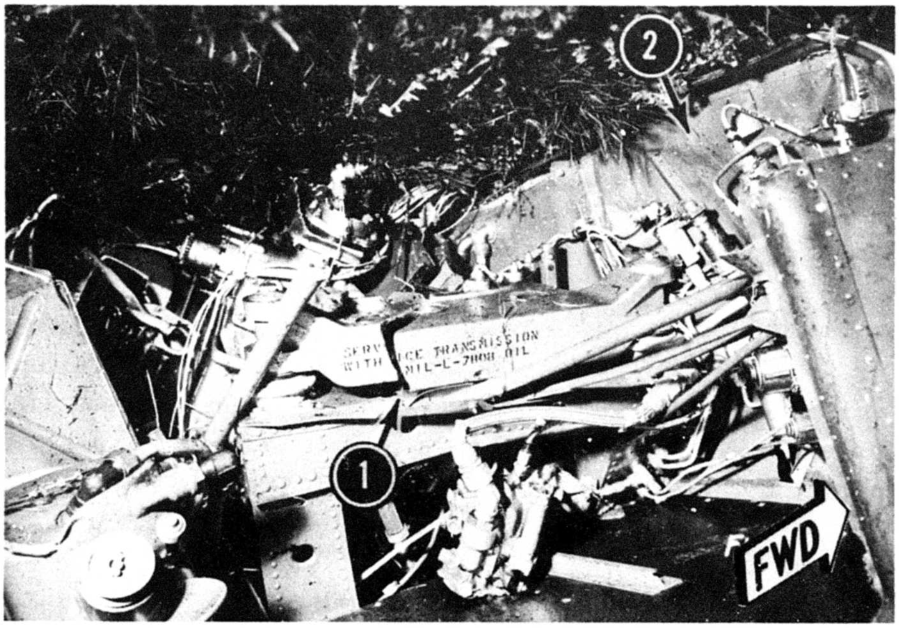


Fig. 48. Transmission mount (arrow 1) was cracked; transmission, rotor mast, rotor head and blades broke off completely to the left. Forward firewall bulkhead (arrow 2) is pointed out for orientation.

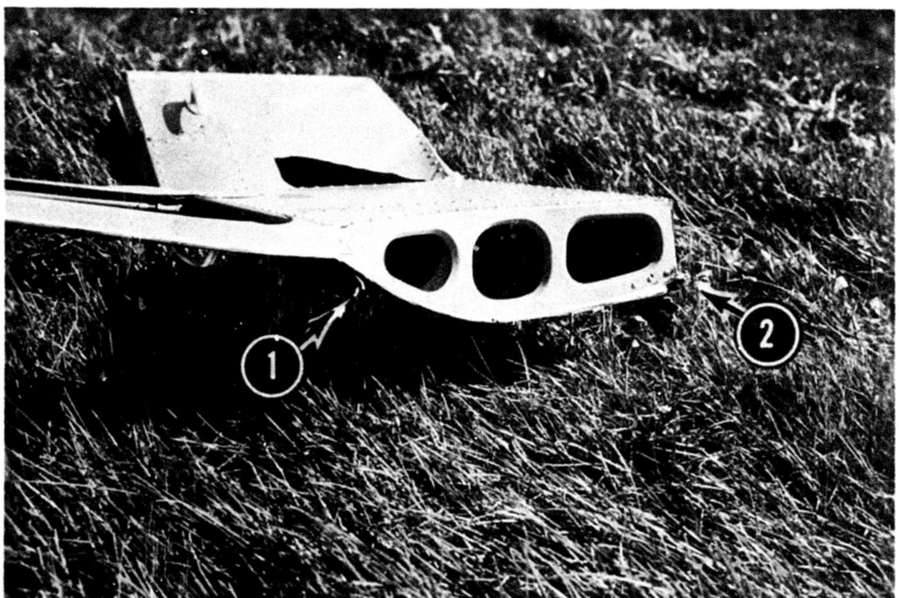


Fig. 49. Right front (pilot's) door, which was torn partially free at initial impact, was found at a point approximately 210 feet along the crash path. Both the upper (arrow 1) and the lower (arrow 2) hinges failed.

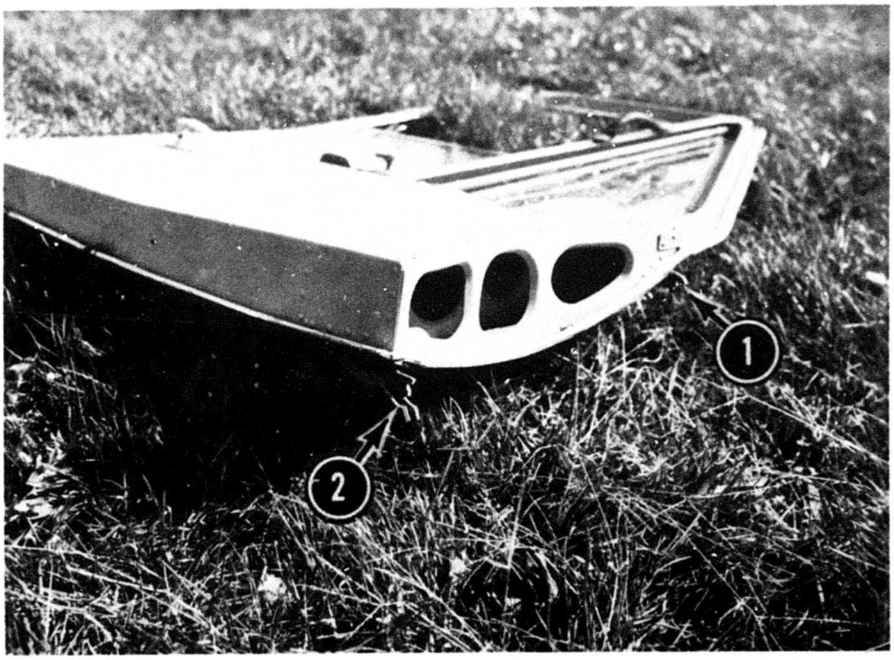


Fig. 50. Left front (copilot's) door, which was also torn partially free at initial impact, was found approximately 175 feet along the crash path. Both the upper (arrow 1) and the lower (arrow 2) hinges were torn free.

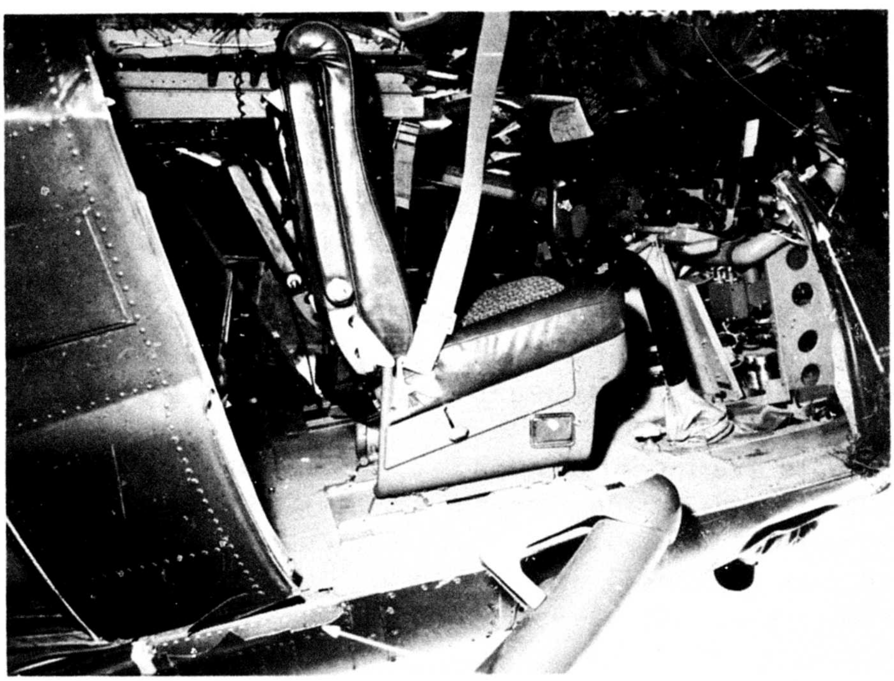


Fig. 51. Close-up of pilot's environment (right side).

CRASH INJURY ANALYSIS

At the final stage of the crash the aircraft went over onto its back, causing the roof structure to collapse into the occupiable area, where it came to rest on top of the pilot's and crew chief's seat backs, as previously described.

Information from the crew chief indicates that, as the aircraft rotated clockwise, both he and the pilot were thrown to the left and forward. Even in their furthermost flexed-forward position, neither the pilot nor the crew chief struck his head on the instrument panel. This sideward and downward deflection also saved them from serious head injuries in the collapse of the roof.

The only serious injury occurring in this crash was the lumbar spinal injury sustained by the pilot. (See Medical Report in Appendix I). This spinal injury suggested that a critically high vertical force had been applied through the seats and prompted a thorough examination of them. This examination revealed no damage other than a slight distortion to the right. (See Figs. 37-38, pp. 24-25).

The seats and the seating configuration in this aircraft differed from those normally found in the HU-1A. Heavier upholstered seats had been installed throughout and a row of three had been added across the center of the cabin. Three seats replaced the three- or four-place bench across the aft end of the cabin. (See Figs. 52-55, p. 33 ff., for views of seats and seating configuration).

The pilot's and the copilot's seats were individually mounted on large, flat supporting plates with tracks for forward and aft adjustment. (See plates and track fittings in Figs. 56-58, p. 35 ff.). The three individual seats across the center of the cabin were mounted on one large plate. The triple seat across the aft end of the cabin was supported by tubular structure in the usual manner for Army troop seats.

The seats are model TE 432F-2, constructed on a frame of chrome-moly aircraft-grade tubing (SAE 120), and have a cushion of 4-inch polyurathane foamed material. The seat pan is a sheet of nylon, impregnated with neoprene, drawn very tightly over the tubular frame and bonded securely. (See Figs. 59-63, p. 36 ff., showing stripped seats).

Fig. 52. An HU-1A (right) is shown alongside the Bell 47J (left) for size and configuration comparison. The HU-1A seats and configuration illustrated are the same as those of the one involved in the accident.

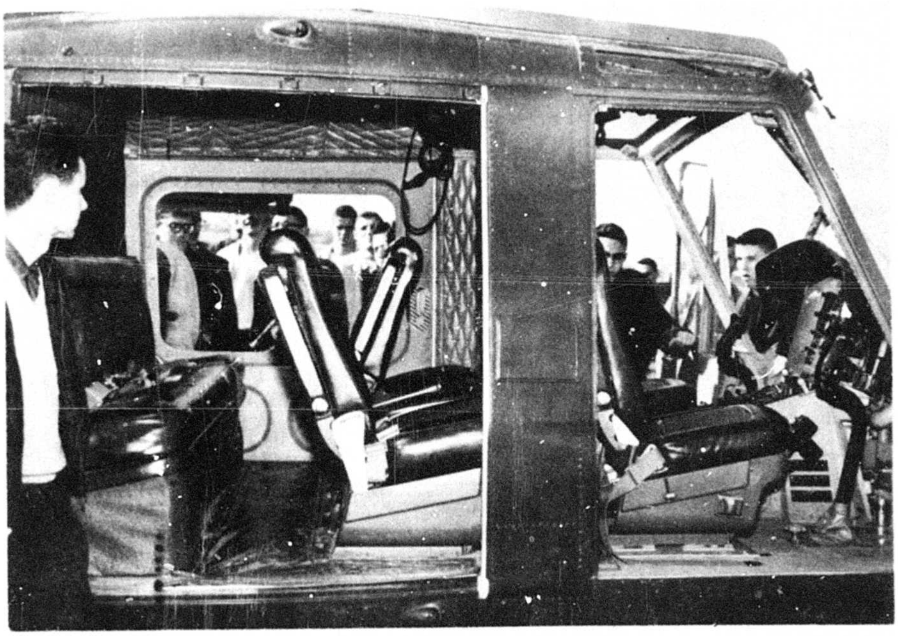


Fig. 53. Right side of HU-1A, showing installation of demonstration-type Teco seats (Model TE 432F-2). This photo was taken just prior to the flight on which the accident occurred.

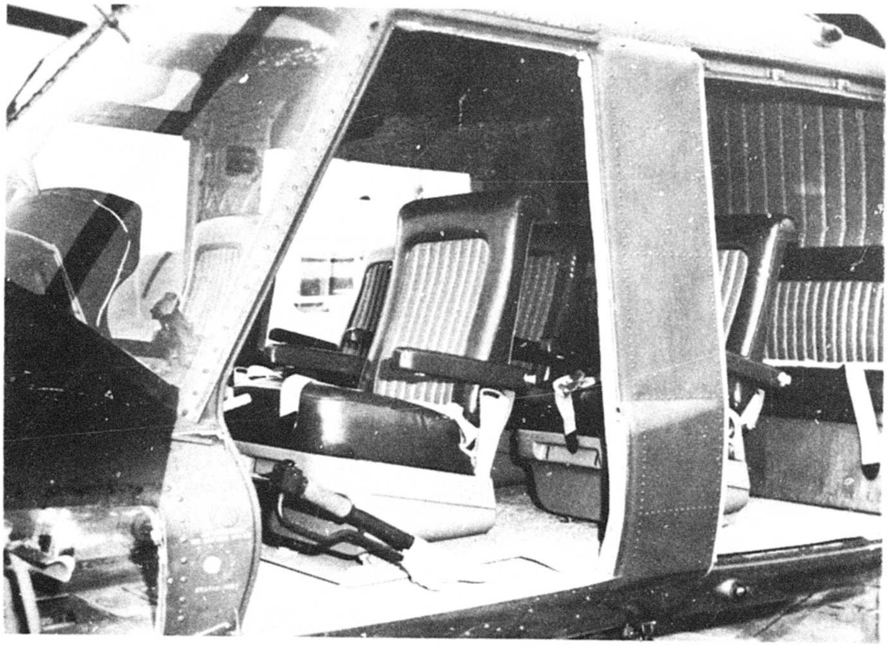


Fig. 54. Left side view - Bell Helicopter Corporation Photo - manufacturer's configuration. Note: The seats illustrated are not those normally utilized in the HU-1A helicopter. These seats were specially installed in this aircraft, which was to be used for demonstration and recruiting programs.

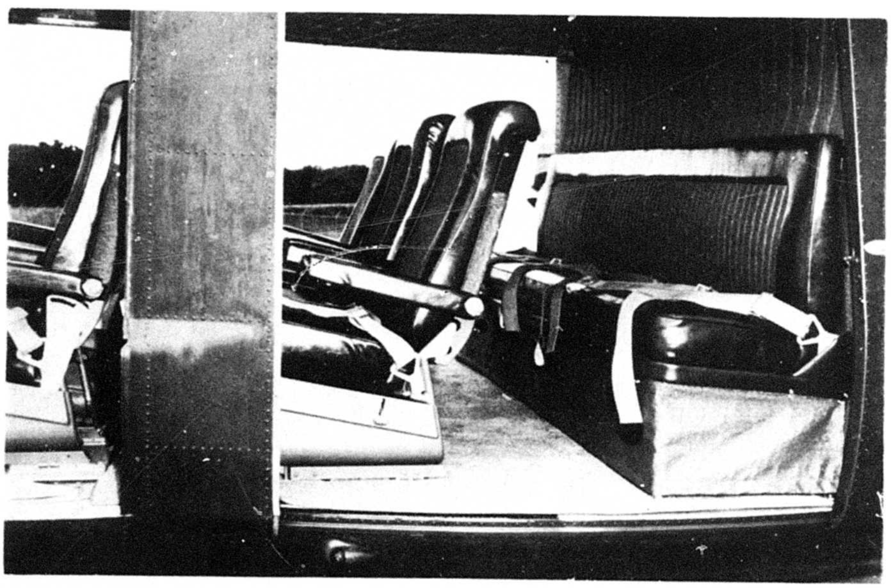


Fig. 55. Left side view - aft cabin - Bell Helicopter Corporation Photo - manufacturer's configuration. The front seats are for pilot and copilot (visible). The 3 individual seats in the second row are passenger seats, as are the 3 bench seats across the back. The individual seats are the type normally used in the Aero Commander.

Fig. 56. Pilot's seat is shown installed in the HU-1A. Mounting plate, upon which seat tracks were mounted, was held to aircraft floor with 16 bolts.

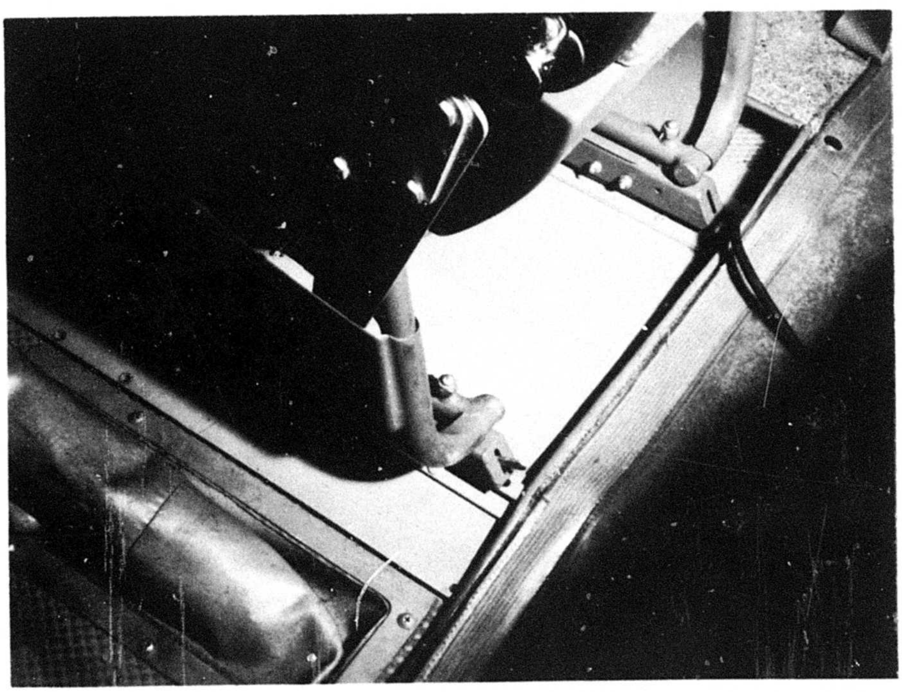


Fig. 57. Seat tracks on mounting plate afford fore/aft adjustment.

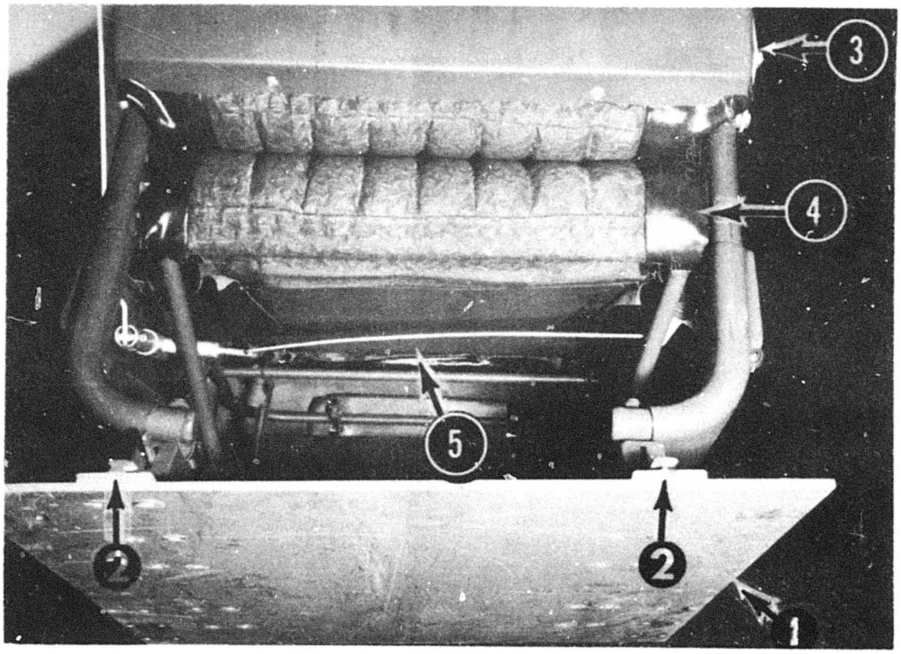


Fig. 58. Seat mounting plate (arrow 1), seat track (arrow 2), seat back (arrow 3), seat cushion (arrow 4), and seat bottom (arrow 5).

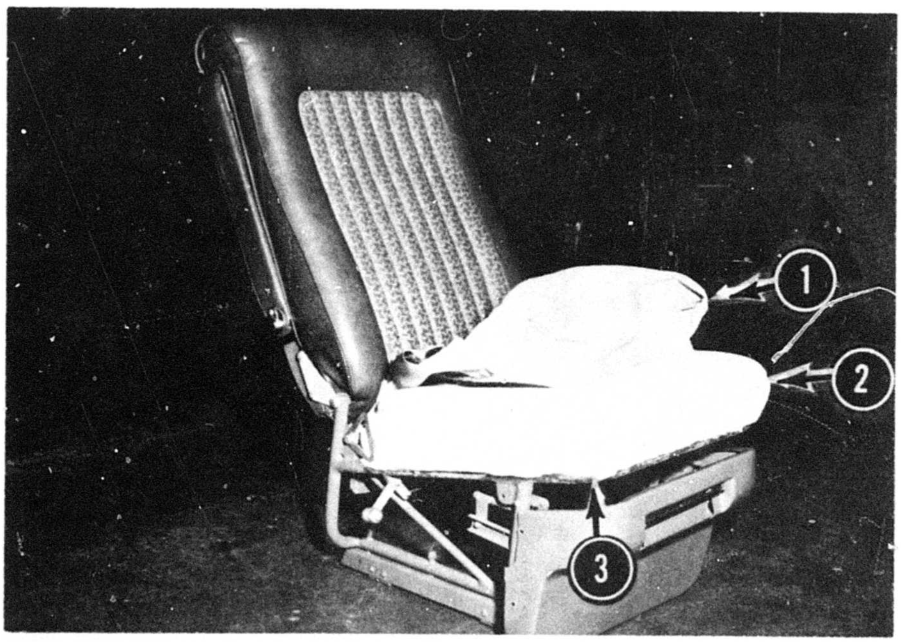


Fig. 59. Plastic (leatherette) upholstery (arrow 1) was removed from the seat cushion, revealing a 4-inch thick cushion of foamed polyurathane (arrow 2). This cushion was cemented to the top of the seat pan (arrow 3).

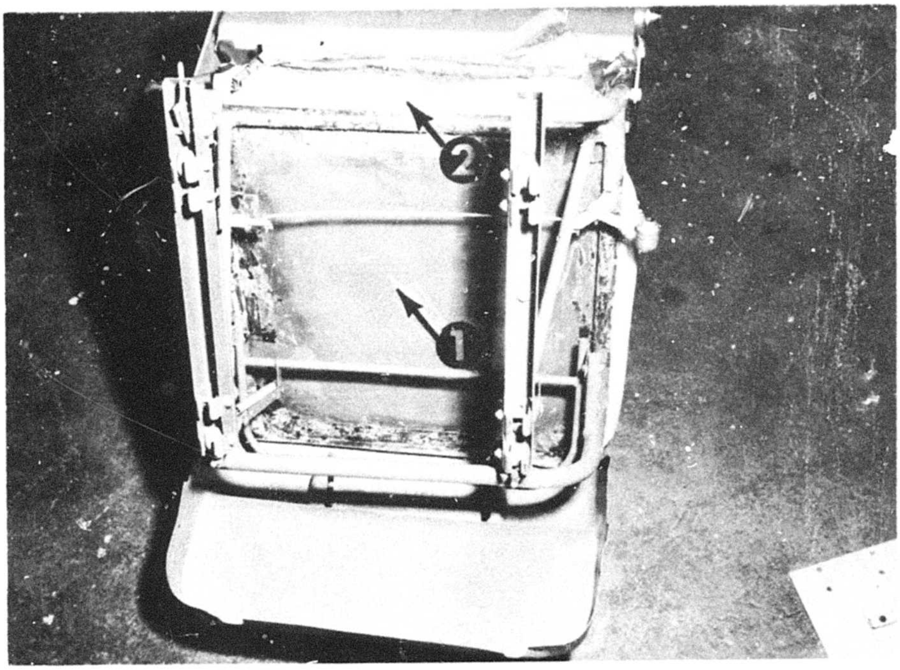


Fig. 60. The bottom of the seat pan (arrow 1) is a sheet of nylon material impregnated with neoprene. This sheeting has been stretched tight over a frame of chrome-moly tubing (SAE 120) and bonded to the tubing (arrow 2).

Fig. 61. Polyurathane cushion, cemented to the neoprene-impregnated nylon seat pan, is removed. The seat pan does not appear to have any degree of yield or stretch.

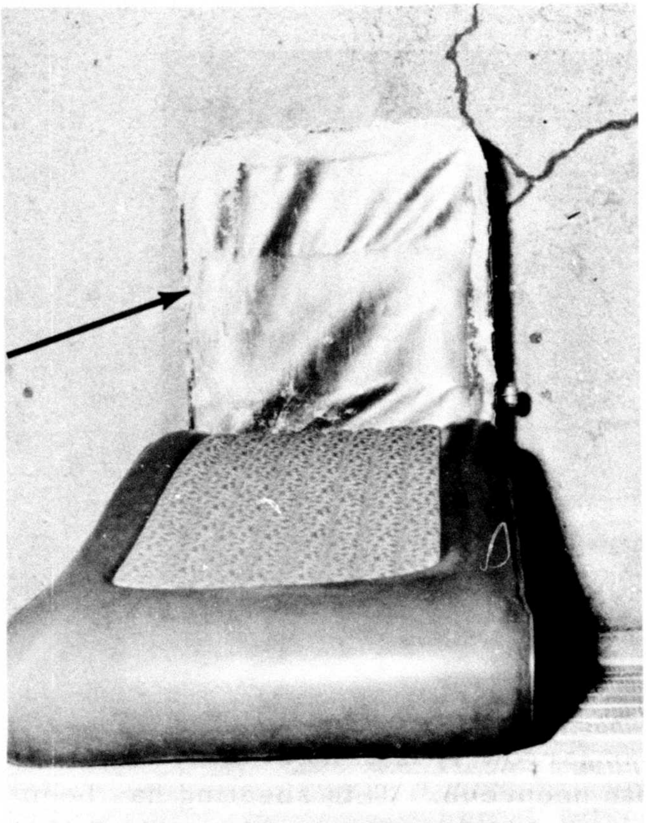


Fig. 62. Top view of seat pan.

Fig. 63. Side view of seat pan.

What appears to have happened is that during the vertical deceleration at initial impact, the aircraft dissipated all its vertical velocity in a stopping distance of about 15 inches, sustaining a mean deceleration of approximately 9.8 G's vertically. (See Appendix II).

The load acting on the occupants probably exceeded 9.8 G's, however, since they were sitting on polyurathane foamred seat cushions. The lack of sufficient energy absorption characteristics of this material would allow the occupants to "bottom" suddenly against the rigid seat pan during the aircraft's vertical deceleration. The resulting jolt load would have to be added to the 9.8 G's already acting on the seat structure. This load amplification may well explain the spinal injury of the pilot. * It is normally considered possible for the human body, properly supported, to withstand as much as 24.5 G's vertically without injury to the skeletal structure. **

It is interesting to note that the crew chief, sitting in the copilot's seat, did not receive spinal injuries. A possible explanation may be found in the following:

The crew chief states that he braced himself against the impact by holding onto the seat pan with both hands. In the absence of a shoulder harness this would provide a measure of upper torso support. He may also have pulled himself down into the seat, thereby compressing the seat cushion and decreasing the bottoming distance.

Another factor that must be considered is the difference in leg positions of the pilot and the crew chief. The pilot probably had his legs stretched out engaging the controls, while the crew chief likely had his feet on the floor directly in front of his seat. The knee-high position of the latter could have decreased the contact area between his buttocks and the cushion, resulting in a deeper impression in the cushion and less bottoming distance.

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* F. Girling and E. D. L. Topliff, Dynamic Testing of Energy Absorbing Materials, DRB Project No. D50-93-20-02, Defense Research Medical Laboratories, Toronto (Canada), 1958.

** J. P. Stapp, Human Exposures to Linear Deceleration, Part 2. The Forward-Facing Position and the Development of a Crash Harness. Wright Air Development Center, Wright-Patterson Air Force Base, Dayton (Ohio), December, 1951. Report No. 5915, Part 2.

It is felt, therefore, that the pilot suffered spinal injury because of load amplification and that the crew chief escaped such injury by not being subjected to the same degree of load amplification.

The pilot's rib fracture was probably caused by contact with the cyclic stick. What caused his iliac fracture, which was not serious, cannot easily be determined. In spite of his injuries he was able to evacuate the aircraft by himself.

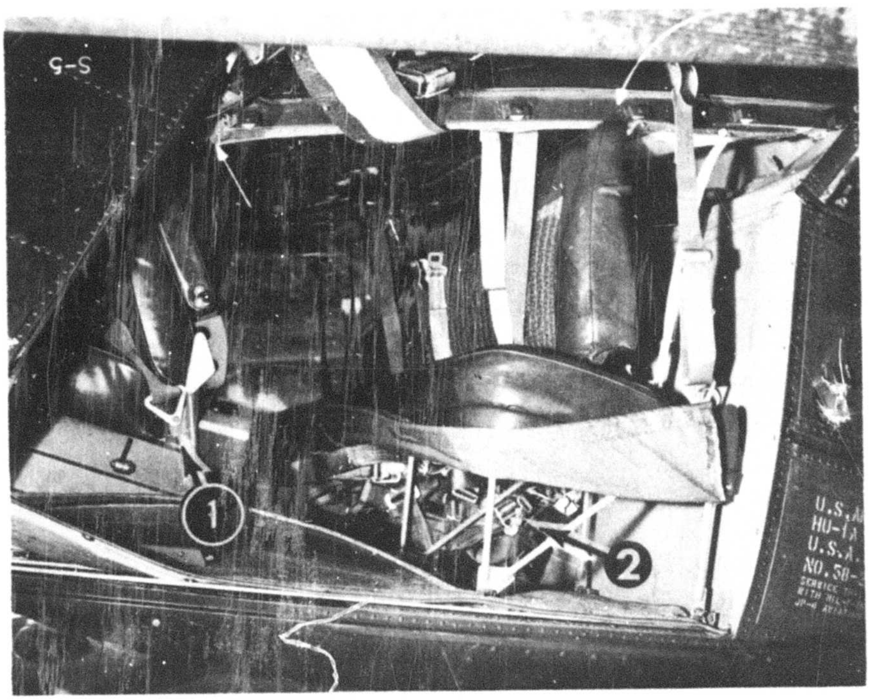

Fig. 64. Safety belt anchorages on single seats are designed to be flexible for force application in one plane only; they pivot on their attaching bolts (arrow 1). Note parachutes and harness stored beneath rear passenger seat (arrow 2).

An estimated vertical deceleration of 6.3 to 14.2 G's (or an average of 9.8 G's) was sustained during the initial impact in this accident. (See Appendix II for detailed calculations of crash force). The landing skids of the aircraft appear to have absorbed a considerable amount of the crash energy. The cross-tubes supporting the skids yielded to permanent set, and energy was absorbed over a vertical distance of approximately 15 inches. (Deformation is shown related to normal position of skids and cross-tubes in Fig. 39, p. 25). The skids were driven upward to a position just about even with the underside of the fuselage. (See Figs. 9-10, pp. 7-8; Fig. 65, below). The belly of the fuselage sustained very little damage except for the aft portion beneath the transmission and engine deck area.

The tail cone and tail rotor assembly broke free as a unit during the initial impact, and the right side of the tail boom was subjected to a great deal of structural damage. (For action photograph of assembly breaking see Fig. 3, p. 6).

Reference is made here to the special seats and the seating

Fig. 65. Right side of helicopter. Cargo door (arrow 1) was out of its track, but still attached to the fuselage. Note inward deformation of "roof" structure and buckling of vertical support member (arrow 2).

configuration discussed previously in the Crash Injury Analysis section. Because these special seats had changed the normal center of gravity of the aircraft, lead weights had been added to the extreme aft end of the tail boom and molten lead had been poured into the tail skid. This extra weight amounted to about 60 pounds of concentrated mass at the extreme end of a moment arm from the tail boom attachment point. This extra concentrated mass probably had a great deal to do with the tail boom's breaking downward at the initial impact. If it can be assumed that the aft end of the aircraft also sustained an average crash force of 9.8 G's vertically, then this extra 60 pounds could be multiplied to almost 600 additional pounds at the extreme end of the tail boom. That 600 pounds at the end of a 10-foot moment arm (length of the tail boom) would become 6,000 foot-pounds and was probably an important factor in the tail boom's breaking downward at the initial impact.

Analysis of the problem of why the roof impinged to such a great degree on the occupiable area of the aircraft is centered about two basic questions:

1. What structure supports the roof?

2. At what point during the crash sequence did the roof finally crush inward?

First of all, the roof is supported at its aft end on a secondary type of structure; that is, the aft firewall bulkhead. (For distortion of bulkhead see Figs. 26-29, pp. 19-20). About two-thirds of the way forward from this point it is supported on the left and the right by vertical support members. During this accident both of the vertical support members failed outward in compression and allowed the forward portion of the roof to come down into the cabin. (See Figs. 18-19, p. 15; Figs. 66-74, p. 43 ff). The aft end, supported by the bulkhead, failed aft as the upper portion of the bulkhead failed in compression; as a result, the aft end of the roof moved aft and downward.

The extreme forward portion of the roof is supported by the front door frames and a center strip of the windshield frame structure. (See structural drawing and photographs of damage in Fig. 17, p. 14; Fig. 67, p. 44). Both forward door frame members and the windshield frame in the center failed completely, and the forward edge of the overhead structure crushed inward 18 to 24 inches.

Further analysis of the vertical support members on the right and the left of the cabin indicates that the lower attaching points for

these members consisted primarily of two "L" stringers, one fore and the other aft. The outer and the inner skin of this vertical support member are attached to the outer skin and the floor respectively. The upper attachment points did not appear to have the structural integrity of the lower attachment points. (See Figs. 70-74, p. 45 ff. for damage details in vertical support members.)

The primary structure of these vertical support members appears to have been riveted to the upper forward portions of the sliding track for the cargo doors and attached by the outer and the inner skin of the vertical support members.

The two 67-1/2 gallon fuel tanks located to the left and to the right of the hoist mechanism, just below the transmission deck of the aircraft, appear to have held up very well during the crash sequence. (See intactness of tank area in Fig. 30, p. 21). No fuel spillage was noted. The tanks did not rupture, although the outer tank walls sustained some damage.

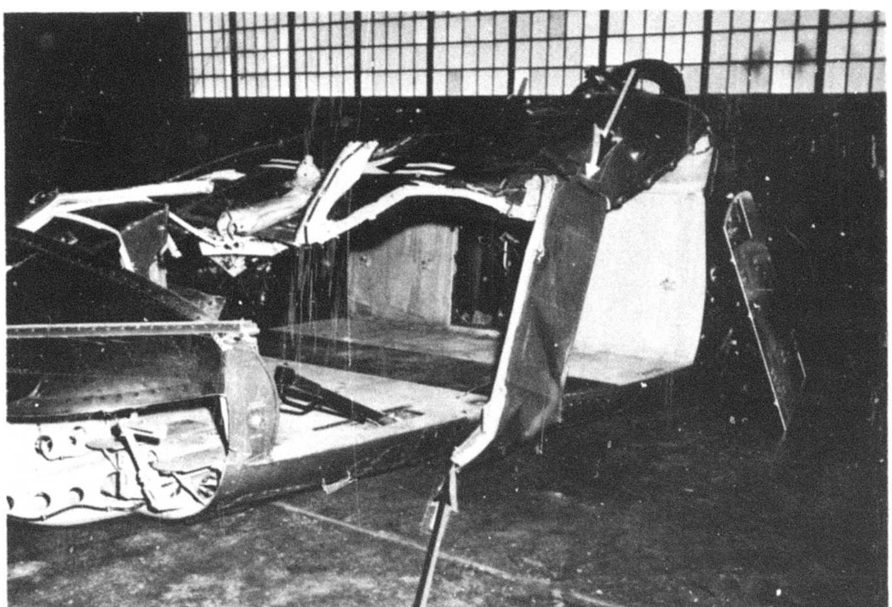

Fig. 66. Left side of fuselage (seats removed). Vertical overhead support (arrows) failed. (See Fig. 67).

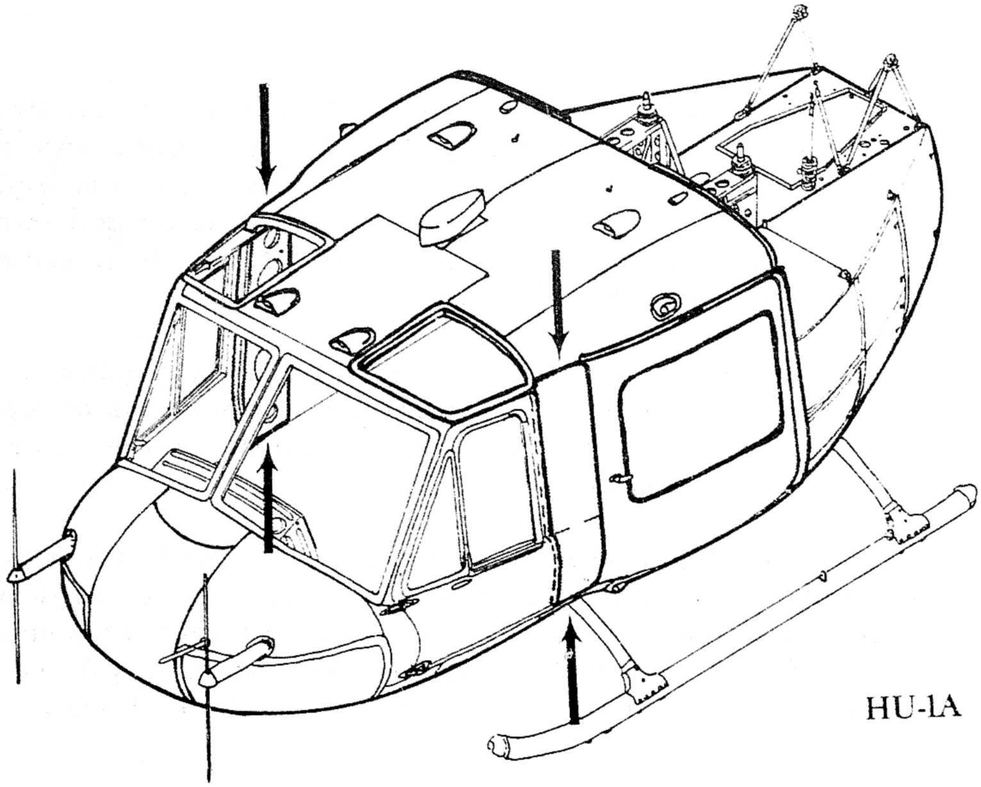

Fig. 67. Reference drawing to illustrate structure referred to in Figs. 45 and 46.

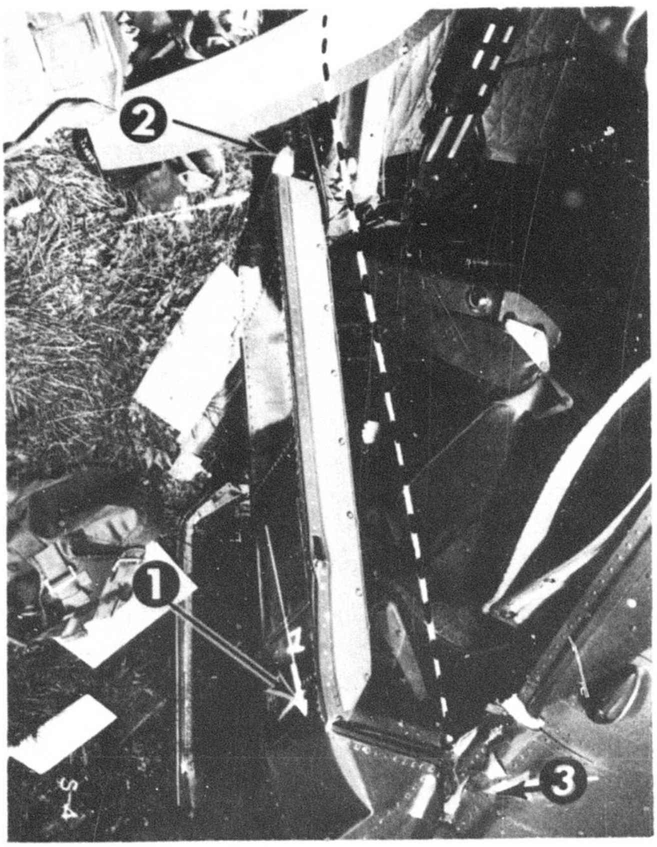

Fig. 68. Left support member, aft edge (looking forward). Note compression buckling (arrow 1). Dotted line indicates normal position. Failure of this member occurred both at the top (arrow 2) and bottom (arrow 3) attachments.

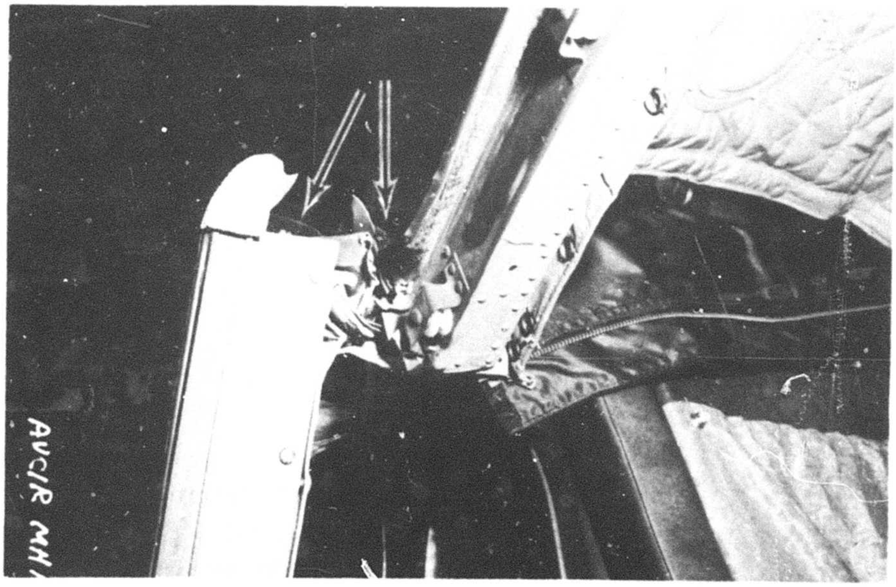

Fig. 69. Left support member, aft edge, top (looking forward). Failure (arrows) is believed to have occurred during final rolling of the fuselage onto its back. Failure of this structure <u>outward</u>, as it occurred, is more desirable than failure inward would be.

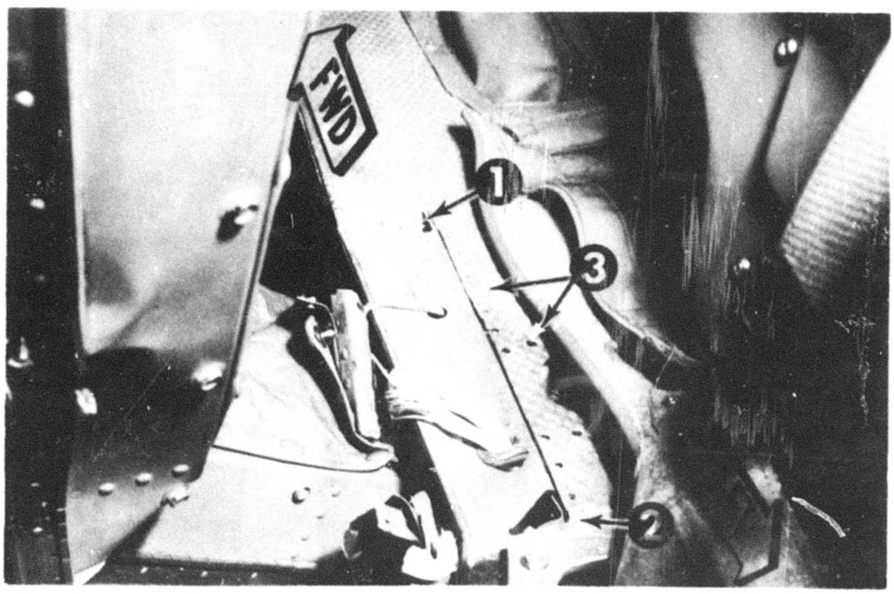

Fig. 70. Left support member, lower attachment points. The triangular cutouts (arrows 1 and 2) allow "L" stringers to pass through vertically. The "L" stringers and the inner and outer skin of the support member attach the member to the fuselage. The line of rivet holes (arrow 3) indicate where the skin attaches to the floor.

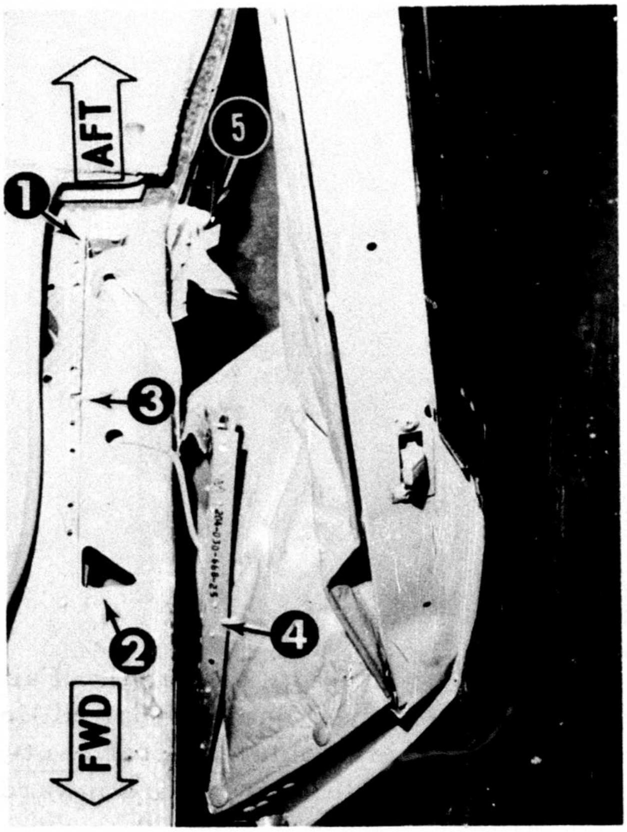

Fig. 71. Structural integrity of the vertical support member (which also serves as door frame for forward and cargo doors) depends on the strength of "L" stringers (arrows 1 and 2) and of the inner skin attachment method (arrows 3 and 4). The outer skin attachment system is pointed out by arrow 5.

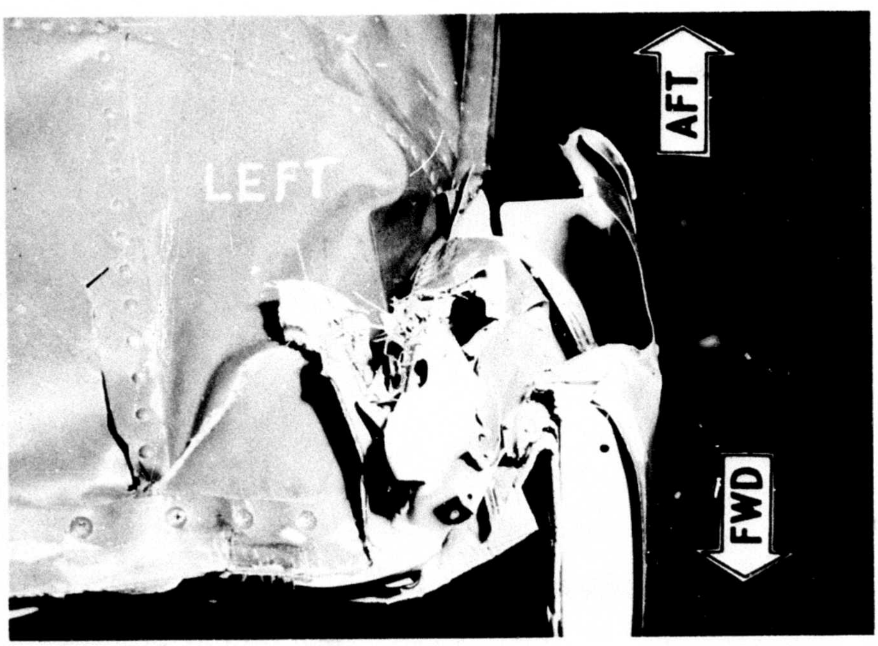

Fig. 72. Left vertical support member, upper attachment point. It does not appear that the "L" stringers extend up to the top of this member for attachment. Inner and outer skin appears to be largely relied upon, in addition to other structural attachment methods, to provide integrity.

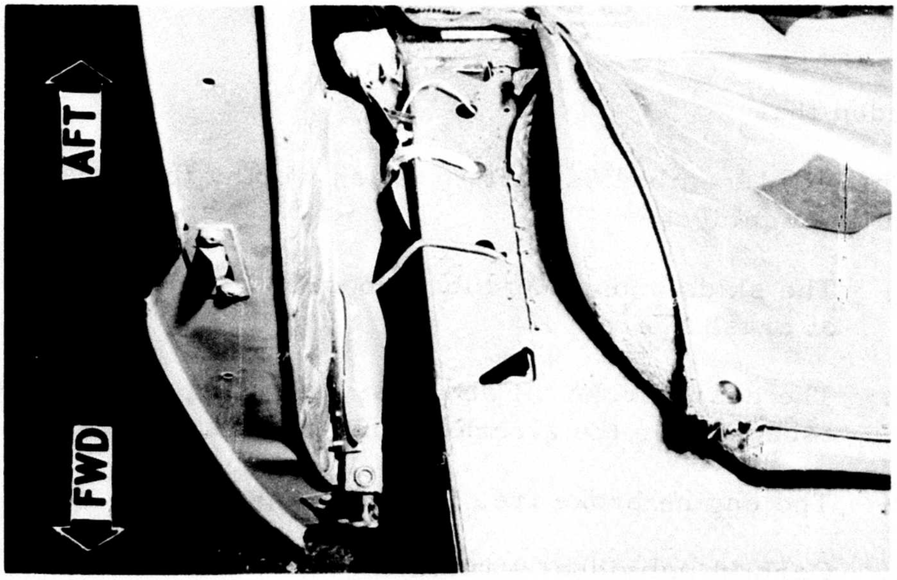

Fig. 73. Right vertical support member, lower attachment point. Failure of this area is essentially the same as the left. Forward and aft "L" stringers and outer skin and inner skin attachments all failed, a condition that allowed the support member to tear free.

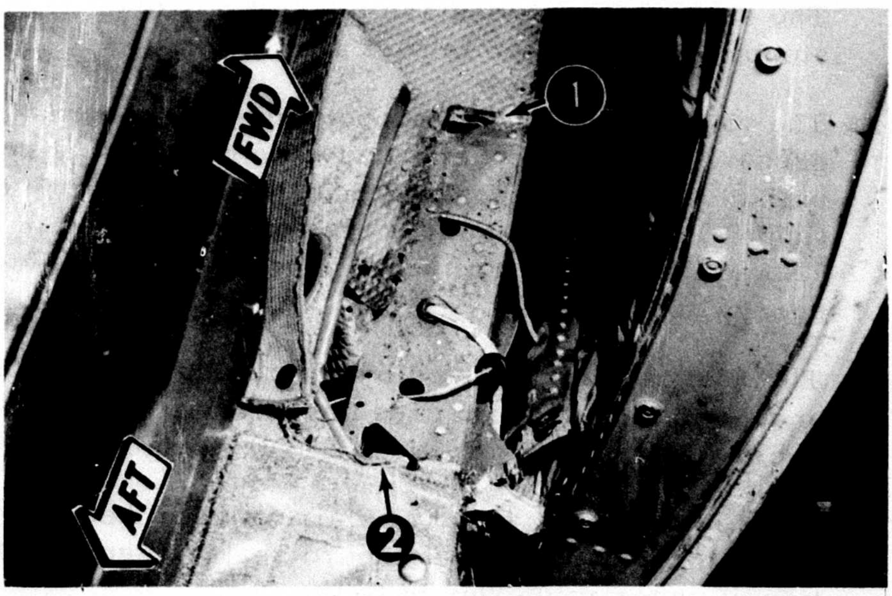

Fig. 74. Right vertical support member, lower attachment point. Depth and type of failure of forward "L" stringer is shown by arrow 1 (as compared to that of aft "L" stringer). Arrow 2 indicates some application of force against the upper area of the member in an aft direction during its failure.

CONCLUSIONS

It is concluded that:

1. The HU-1A embodies certain crash worthy features, as shown in this accident:

   a. The skids and cross-tubes abosrbed a considerable degree of crash energy.

   b. The doors broke off and away, allowing large exits for escape when the aircraft came to rest.

   c. The engine broke free in the best possible way.

   d. Certain individual structural units, such as the ceiling and the floor, are quite strong.

   e. The fuel cells are located in an area not highly subject to impact damage and probably for that reason did not rupture.

2. Deficiency in crashworthiness exists in the following respects:

   a. The seat cushions used are too soft to provide an effective stopping distance for impact alleviation.

   b. The rigidity of the seat-supporting structure makes a progressive collapse under survivable crash force conditions unlikely. (It is recognized that the seats used in this particular aircraft are not the type normally used in the HU-1A and that the normal seats provide a certain degree of energy absorption.)

   c. The roof is not supported by vertical members strong enough to keep it from crushing down into the cockpit and cabin areas under conditions of survivable crash force.

   d. The center of gravity of this aircraft had been altered by installing heavier than standard seats, requiring the addition of undesirable weight to the tail.

   e. Shoulder harness was not installed in this aircraft. Although the absence of more serious injury in this accident can be attributed to an unusual coincidence (the lack of shoulder harness and weakness of the roof-supporting structure), there is no reason to discredit the proven value in survivable accidents of a properly installed and worn shoulder harness.

RECOMMENDATIONS

It is recommended that:

1. Immediate attention be given toward increasing the integrity of the overhead structure of the HU-1A to prevent it from impinging on the cockpit and cabin areas under survivable crash force conditions. A suggested solution to this problem would be to install a roll-bar structure in the fuselage.

2. Any seats and seat cushions used in this type aircraft be of a type which will provide sufficient vertical crash energy absorption to prevent injury under survivable crash force conditions.

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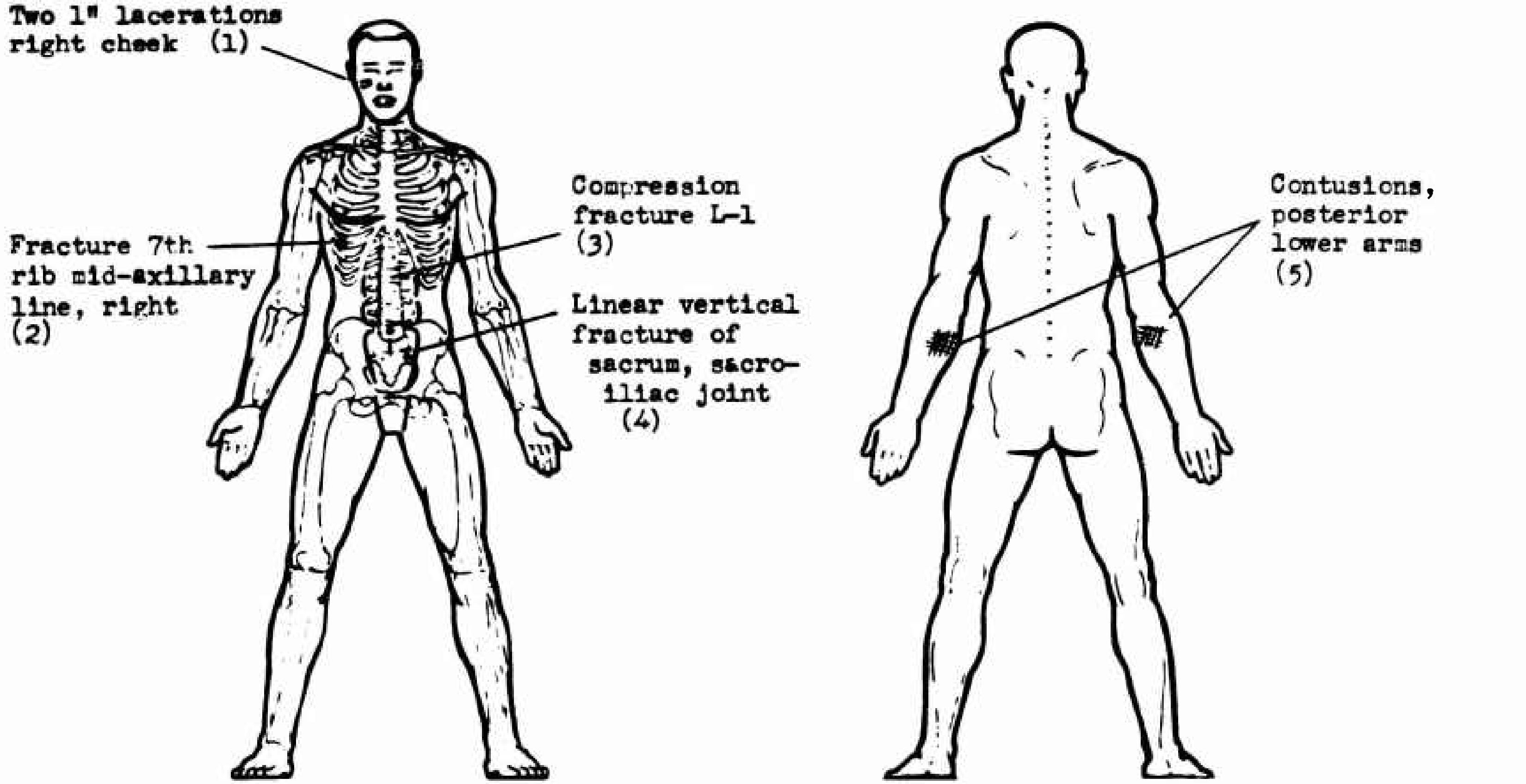
APPENDIX I

MEDICAL REPORT FORMS

APPENDIX I - MEDICAL REPORT

PILOT - Right Seat



1. Cause undetermined
2. Possibly caused by striking cyclic
3. Possibly result of load amplification
4. Cause undetermined
5. Cause undetermined

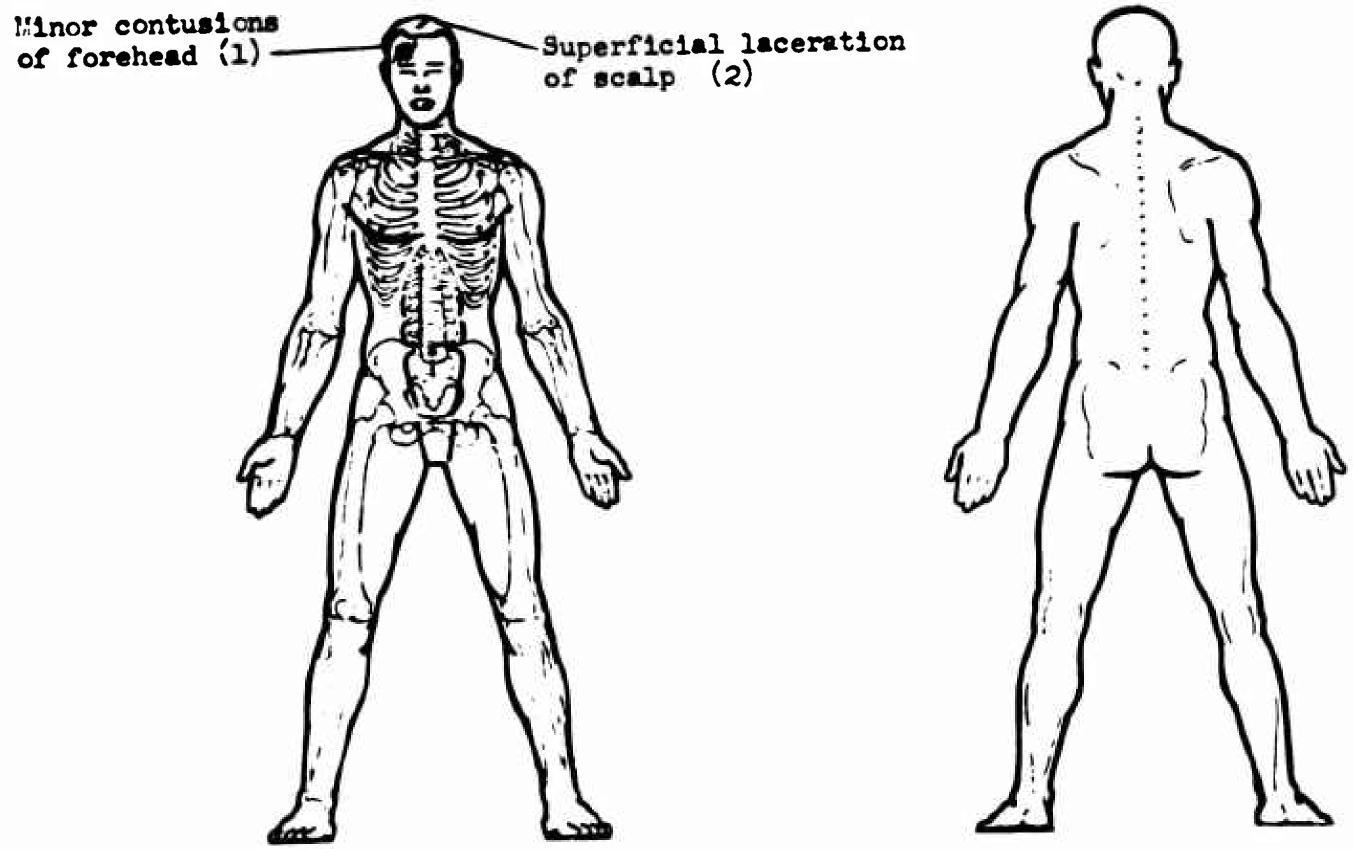
Height 5' 11½" Weight 195 Sex M

Remarks:

Patient well oriented after accident; no shock.

APPENDIX I - MEDICAL REPORT

CREW CHIEF - Left Seat



1. Cause undetermined
2. Cause undetermined

Height 5' 10" Weight approx. 160 Sex M
Remarks: None

APPENDIX II

CRASH FORCE ANALYSIS

In the absence of instrumentation as used in experimental crashes, the calculation of the decelerative forces during the initial impact had to be based upon eyewitness accounts, photo interpretation, and post-crash measurements of gouges and structural damage. The results of these calculations, therefore, must be considered as approximations.

The flight path angle was estimated at 18 to 23 degrees; the flight path velocity was estimated at 40 to 50 knots. The vertical stopping distance (15 inches) is the known distance between the fuselage and the ground plus the depth of gouge.

Impact velocities of 40, 45, and 50 knots, in combination with impact angles of 18 and 23 degrees respectively, produced the following vertical velocity components: 22.5, 24.7, 27, 29, 31.5, 34 feet per second.

The average value of these vertical velocities is 28 feet per second. This average vertical velocity, in combination with a vertical stopping distance of 15 inches, would indicate a mean value of 9.8 G's vertically. The duration, determined by distance and average speed, was found to be 0.09 second. The rate of onset was approximately 218 G's per second.

The information available was insufficient to make an estimate of the horizontal deceleration during the initial impact. However, since no signs of extensive gouge marks were found and since longitudinal compression of aircraft structure was negligible, it seems reasonable to assume that the horizontal deceleration was considerably less than the vertical deceleration.

By estimating the coefficient of friction (μ) between the aircraft and the terrain involved as 0.4 and using the formula $G_h = \mu G_v$, an approximation of the horizontal deceleration was made:

$$G_h = (0.4)\ (9.8) = 3.92 \text{ G's}.$$

This calculation is based upon the general assumption that the principal horizontal and vertical decelerations in such impacts take place simultaneously.

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